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THE USE OF AVAILABILITY MODELS IN INITIAL PROVISIONING.(U)

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THE USE OF AVAILABILITY MODELS IN INITIAL PROVISIONING

April 1981

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EXECUTIVE SUMMARY

This report examines two fundamentally different approaches to the computation of requirements in initial provisioning. One approach involves the use of availability models. An availability model is a mathematical model that determines the relative worth-versus-cost of a wide range of possible quantities of spares of each of a system's components and finds the optimal mix of spares for any specified level of weapon-system availability. Thus, availability models take a system view in that they look across all of the components in a system and take explicit account of both cost and readiness in computing the best spares mix.

The second approach is an item-oriented approach prescribed by DoDI 4140.42; it consists of provisioning a pipeline's worth of spares at each below-depot echelon and a pipeline's worth plus a three-month procurement cycle/safety level at the depot for all components that are demand-supported. It also prescribes stockage criteria for non-demand-supported items, i.e., numerical-stockage-objective (NSO) and insurance-type items. Thus, it involves the computation of spares requirements on an item-by-item basis with no explicit consideration of readiness. Although DoDI 4140.42 allows the use of availability models, it requires that the total spares cost that results from the item-by-item computation be used as a constraint on spares investment. A consequence is that the item-by-item computation implicitly not only constrains the spares investment level but also constrains the <u>readiness</u> of a weapon system during its early life.

Clearly, any provisioning technique that does not take end-item availability explicitly into account will never be more cost-effective than

one that does. This is the principal reason that the item-oriented approach of DoDI 4140.42 does not provide cost-effective initial provisioning investment solutions.

We wish to make clear that availability models of the type we describe in this report depend on the availability of component-level data; therefore, they are not useful in establishing the level of dollar resources required for spares during the earliest planning, programming, and budgeting activities in the life of the typical new weapon system. On the other hand, as soon as component-level data become available, even if those data are only estimated, availability models become powerful tools for establishing spares dollar requirements and for computing the best mix of items for any specified total investment cost. The problem of determining dollar requirements prior to the availability of component-level data is not addressed in this report.

The most compelling conclusion that emerges from this work is that across a wide range of weapon systems and scenarios, availability models constitute a significantly more cost-effective approach to initial provisioning than the item-oriented approach. Thus, they provide the opportunity to minimize spares investments while still providing effective weapon-system support.

Other conclusions are supported by this work:

a. The weapon-system availability resulting from the use of an availability model is less vulnerable to uncertainty than that resulting from the use of the item-oriented technique.

b. The policy maker should view all echelons of the logistics system as an integrated whole. Policies that treat the "wholesale" and "retail" levels separately are bound to be less cost-effective.

c. Arbitrary constraints on the quantities of certain line items or sets of items or on echelons of stockage are not cost-effective; in fact, they actively militate against optimality in terms of availability and cost.

d. The belief that the item-oriented approach described in DoDI 4140.42 works well for high-density, low-reliability systems is not correct. Availability models provide more cost-effective mixes of spares than the item-oriented approach for the entire range of force-aggregation/reliability combinations.

We recommend that the ASD(MRA&L):

1. Require specification of availability goals and computation of availability-vs.-cost curves and initial provisioning stockage postures for all new major weapon systems for review by the DSARC prior to full-scale production.

2. Revise DoDI 4140.42

(a) to require the use of availability models and availability-vs.-cost curves in initial provisioning for all new major weapon systems,

(b) to remove any constraints that force availability models to deliver suboptimal stockage postures, and

(c) to require that all echelons of the logistics system be treated as an integral whole in computing stockage postures.

3. Take steps to further the development of provisioning requirements computational methods that incorporate:

(a) techniques for quantifying and modelling the uncertainty surrounding component characteristics,

(b) techniques for estimating <u>expected</u> component cost where the risks of design changes and obsolescence are taken into account, and

(c) techniques for pooling judgments about component characteristics and for modifying those judgments optimally with test and operational data.

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1. A DISCUSSION OF INITIAL PROVISIONING ISSUES

The fundamental problem in initial provisioning (IP) is to find a strategy for acquiring spares that will provide a specified level of weapon-system availability for the least total cost. We will use the terms availability, end-item availability, and weapon-system availability interchangeably here; we mean the probability that an end item, such as a tank or aircraft, selected at random, is not waiting for a component to be repaired or be shipped to it. (We do not mean spares availability, fill rate, or supply effectiveness rate.)

The purpose of the analysis described in this report is to examine the utility of availability models to help gain some leverage on the IP problem. What we mean by an availability model is a mathematical model that maximizes end-item availability for a specified cost, or minimizes cost for a specified level of availability. There are several availability models already in operational use within the DoD that generally satisfy this definition. There is another group of optimization models in use that minimize expected (time-weighted) backorders for a specified cost. The remarks made about availability models throughout this report generally apply to models in both groups since the mix of spares computed by both are almost identical; however, if a model focuses on expected backorders and can not be used easily to produce an availability-vs.-cost curve, its utility in initial provisioning is dramatically reduced. One availability model is of special interest because it was used for the analyses of four Army weapon systems that are discussed in Chapters 2 and 3. That model is referred to as SESAME (Standard ERPSL Spares Allocation Methodology); it was developed by the U.S. Army Inventory Research Office. More is said about SESAME in later chapters.

We emphasize here that, throughout this report, we refer only to recoverable (repairable) spares, not to consumables.

We also refer, throughout this report, to the cost-effectiveness of stockage postures. A stockage posture is simply a set of stock levels of spares by location, for all components in an end item. We measure the effectiveness of a stockage posture by the expected end-item availability that it yields. We consider availability to be the single most important, most direct, and most meaningful measure of performance of an inventory system. We assume that we buy spares to enhance availability. We subordinate all other measures of effectiveness to this one. If we say that stockage posture A is more cost-effective than stockage posture B, we simply mean that posture A delivers more availability per dollar invested, across a wide range of investment levels (or, in certain contexts, at a specified investment level), than does posture B.

In the IP context, the concepts of availability and total cost are substantially more complicated than in the peacetime, steady-state world of spares replenishment. In the steady-state situation, availability is typically computed at a point in time based on the important assumption of stability in the inventory of end items and the operating program for some period of time ahead of the point in time for which the availability is computed. Clearly, these assumptions (and others we shall discuss later) are violated in the IP context. IP is done for the typical weapon system at a time when the end-item inventory is changing, engineering changes are being made, item characteristics (already a matter of uncertainty) are changing, and, perhaps, deployment plans and other system-level characteristics are still changing. Thus, although the fundamental IP problem has characteristics similar to the spares replenishment problem, it is considerably more difficult. The concept of availability takes on a new dimension, time. It is

important in the IP context to think of availability as a function of time, just as end-item inventory size and component characteristics can be viewed as functions of time.

The concept of total cost is also more complicated in the IP context because it, too, has additional dimensions. Component unit prices are among the things about which uncertainty exists. Furthermore, obsolescence costs induced by engineering changes tend to be incurred in the IP context much more frequently than in the replenishment situation. Thus, it is really total expected cost that we wish to consider in the IP problem, where the expectation recognizes possible futures involving penalty costs.

The need to achieve availability levels that will support training and readiness requirements tends to drive one in the direction of buying substantial quantities of spares early; however, the penalty costs for eventual excesses, obsolescence, or retrofits tend to dissuade one from early investment. The problem is to determine how we can minimize spares investments early in the life of a weapon system and still provide adequate numbers of available end items.

The spares acquisition process for a new weapon system consists of several major steps over a period of four or more years. The process begins with planning for the support of the weapon system, and continues through programming, budgeting, requirements computations, and procurement. With respect to the utility and application of availability models, procurement is not an issue and the remaining steps can be aggregated into two essential ones: (1) determining the level of spares investment and (2) determining the mix of spares in which to invest. The first of these two essential steps we will describe as budgeting (even though more than the budget year is typically involved) and the second as provisioning.

In provisioning, the problem is to compute requirements, i.e., to compute the best mix of spares for any specified level of investment. But, even in this context, the availability-vs.-cost curve is useful because there is still opportunity for tradeoffs of dollar resources within budget programs, across weapon systems, and even across time within a weapon system (for example, by obligating money for some subset of shorter-lead-time items at the very end of the fiscal year). The provisioning problem is, in one sense, less difficult than the budgeting problem because of shorter lead time, hence less uncertainty. On the other hand, it is substantially more difficult because its solution actually specifies quantities of particular line items rather than simply a dollar total, and those item quantities will be tested by all of the vagaries of the operational world. Both problems share a common objective: to provide the resources needed to support a reasonable level of availability while minimizing losses due to excesses, retrofits, and program changes. Therein lies the power of an availability model because of its ability to support, at least beyond the initial budget, the dollar resource decision as well as the computation of the spares mix in a cost-effective way.

In the typical weapon-system acquisition scenario, the need arises to program dollar resources for initial provisioning before a complete list of components to be installed in the weapon system even exists, certainly before any thoughtful estimates of component characteristics have been developed. It is important to realize that an availability model of the type with which we are concerned here is not useful in developing this earliest estimate of investment requirements because it requires component-level data which are not then available; however, the seriousness of the problem of developing such an early estimate tends to be mitigated somewhat by the fact that, until the year for which the estimate is being made actually becomes the budget year in the

PPBS cycle, it is still possible to change the dollar estimate. In fact, even in the current or execution year, dollar resources are still fungible, but to a substantially lesser extent. The military department has the prerogative in budget execution to reallocate dollar resources within budget programs; therefore, funds can be added to some systems and deleted from others as additional visibility of requirements and shortages is gained. Despite the fact that the availability-vs.-cost curve that is computed by an availability model would be a powerful tool in the decision process involved in budgeting, the earliest budget in the typical case is built well in advance of the existence of sufficient data to support such a model. Typically, component-level data are available prior to the first year of production and an availability model can be used to compute an availability-vs.-cost curve that can be useful for budgeting and for budget revisions.

Unsolved, in fact unaddressed in this report, is the problem of computing or estimating an availability-vs.-cost curve prior to the availability of component-level data. An approach to this problem that seems workable is to develop a method to parameterize an availability-vs.-cost curve and estimate the parameters of the curve for a particular weapon system based on its system and subsystem characteristics. The method has not been demonstrated.

With respect to measures of effectiveness for budgeting, it seems clear that, given some target availability, one cannot do better than budget a dollar amount equal to the dollars required to achieve that expected availability at the time of computing spares requirements. With respect to provisioning, the issue is more complicated because the weapon-system availability that is optimized in computations by an availability model is not measured in the operational environment; thus, the comparison is quite difficult and, at best, approximative. A measure of effectiveness that seems

more accessible and, perhaps, even more reasonable, is the comparison of the expected availability computed at the time of spares requirements computation with the expected availability computed at some later point in time when component characteristics are known from empirical observation. This method would produce a measure of effectiveness free from confounding factors of the operational environment such as lateral resupply and cannibalization.

We now discuss further the planning, programming, and budgeting steps in the spares acquisition process.

PLANNING

Several of the availability models currently in use compute an availability-vs.-cost curve, each point of which is an optimum, i.e., it represents a stockage posture that maximizes availability for that particular level of investment and minimizes cost for that particular level of availability. Other models require specification of a numeric value that implicitly determines the investment level and will compute a stockage policy that maximizes availability for that particular investment level. Such a model may be used to repeat that computation several times using different investment levels to produce an availability-vs.-cost curve. In either case, the resulting availability-vs.-cost curve is a very powerful planning tool for a program manager because it explicates the tradeoffs available between weapon-system availability and spares investment dollars.

Very early in a weapon-system program, more is known about its characteristics at the system and subsystem level than at the component level. As the design and development evolve, data at the component level begin to emerge. As the design hardens, the component-level data become increasingly visible and increasingly firm but, prior to any substantial operational experience

with the weapon system, component characteristics remain a matter of considerable uncertainty. During this process of data evolution, the problem associated with supporting availability models and the feasibility and utility of their application change. As we pointed out earlier, in the absence of component-level data, one cannot apply an availability model either to compute spares requirements or to compute an availability-vs.-cost curve. Such models <u>must</u> have a menu of <u>known</u> components from which to develop a stockage posture; however, the <u>characteristics</u> of those components need not be known with certainty. In fact, there are techniques for characterizing uncertainty about components that are very powerful modelling tools in computing stockage postures, availability-vs.-cost curves, and the expected worth of additional testing or experience. We show a simple application of such techniques later in this chapter. Since availability models cannot be used for planning or budgeting purposes prior to the time when component-level data, however unreliable, are available, the need exists to develop techniques that provide some leverage on the problem of estimating investment requirements for spares based on weapon-system and subsystem characteristics that are available prior to the availability of component-level data.

In order to account for an increasing number of operational end items across time, one might plan for spares support of a program for each year's production increment. It may be reasonable in doing that planning to set different availability goals for each year of the system's early life, with the goals changing each year. The feasibility of doing this clearly depends on training and operational requirements that the system must meet during the time of increasing end-item inventory. In any event, the use of availability models facilitates some of the decisions that need to be made in weapon-system-support planning.

PROGRAMMING AND BUDGETING

Programming is simply the translation of planning into annual spares investment requirements for inclusion in the Program Objectives Memorandum (POM). The programming and budgeting process is the means by which dollar resources are eventually allocated to requirements.

Budgeting is essentially programming with a short time horizon where, in fact, the horizon is the budget year. It is the process that translates the first year of a multi-year program into a form that can be submitted to the Congress in the language of congressional budget programs and appropriations. Typically, the budgeting process involves more detailed analyses of requirements and explicit consideration of funding constraints than does programming.

The usefulness of an availability model in this process lies in its ability to compute the cost of the optimal mix of spares for any specified level of availability, by weapon system, by program year (and for the budget year). One model, the LMI Availability Model, will also compute the least-cost mix of spares investment dollars and depot repair dollars; thus, it is an ideal budget planning tool but, again, only when component-level data are available.

REQUIREMENTS COMPUTATION

In the process of computing an availability-vs.-cost curve, an availability model produces a set of requirements that is implicit in the stockage posture it develops. A stockage posture, as we defined it earlier, is simply a set of stock levels by item and location for all of the components in a weapon system. In order to translate a stockage posture into requirements one needs to account for expected condemnations and item receipts during the procurement lead time.

The way in which an availability model operates to produce stockage postures is a highly technical issue that we will not discuss here; however, we do believe it is useful to have some intuition about the differences between optimized postures and classical, item-oriented postures. By an item-oriented posture we mean a stockage posture that results from applying stockage criteria to individual items or sets of items rather than to the weapon system as a whole. A fixed-safety-level criterion, for example, yields an item-oriented stockage posture. We will now try to convey some sense of the differences between optimized stockage postures and item-oriented postures. The reader is urged to ignore the lack of realism in the example that follows. It was designed specifically to be instructive, not to represent any real system.

A SIMPLE NUMERICAL EXAMPLE

We begin by considering a simple numerical example designed to provide some intuition about how an availability model takes advantage of the heterogeneous characteristics of components to compute cost-effective stockage postures.

In this example we consider a two-echelon inventory system consisting of a depot and three bases. There are 30 end items (aircraft, say, or tanks) at each base. Each end item consists of 10 recoverable components, i.e., components subject to repair when they fail. All of the components have exactly the same characteristics except for their unit costs. The item characteristics and unit costs are shown in Tables 1-1 and 1-2, following.

TABLE 1-1

ITEM CHARACTERISTICS	
Base Daily Demand Rate	0.10
NRTS (not repairable this station) Rate	0.50
Pooled Base Daily Demand Rate	0.30
Depot Daily Demand Rate	0.15
Base Repair Time	5 days
Depot Repair Time	45 days
Order-and-Ship Time	5 days

TABLE 1-2

UNIT COSTS

ITEM	COST
1	$ 500
2	1,000
3	2,000
4	4,000
5	8,000
6	16,000
7	32,000
8	64,000
9	128,000
10	256,000

The inventory system operates according to a continuous-review policy; it is described graphically in Figures 1-1 and 1-2. By a continuous-review policy we mean that as soon as stock on hand, plus due-in, minus due-out, falls below the stock level, a requisition is submitted by the base to the depot instantaneously to create another due-in.

FIGURE 1-1

A SIMPLE NUMERICAL EXAMPLE

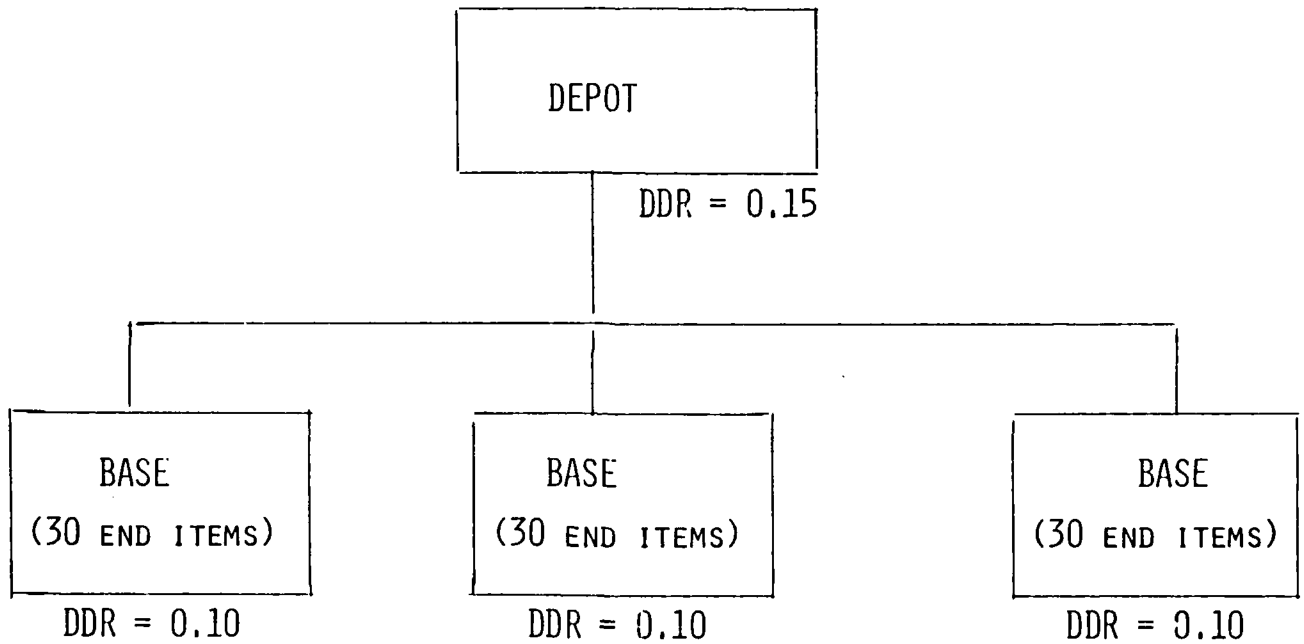
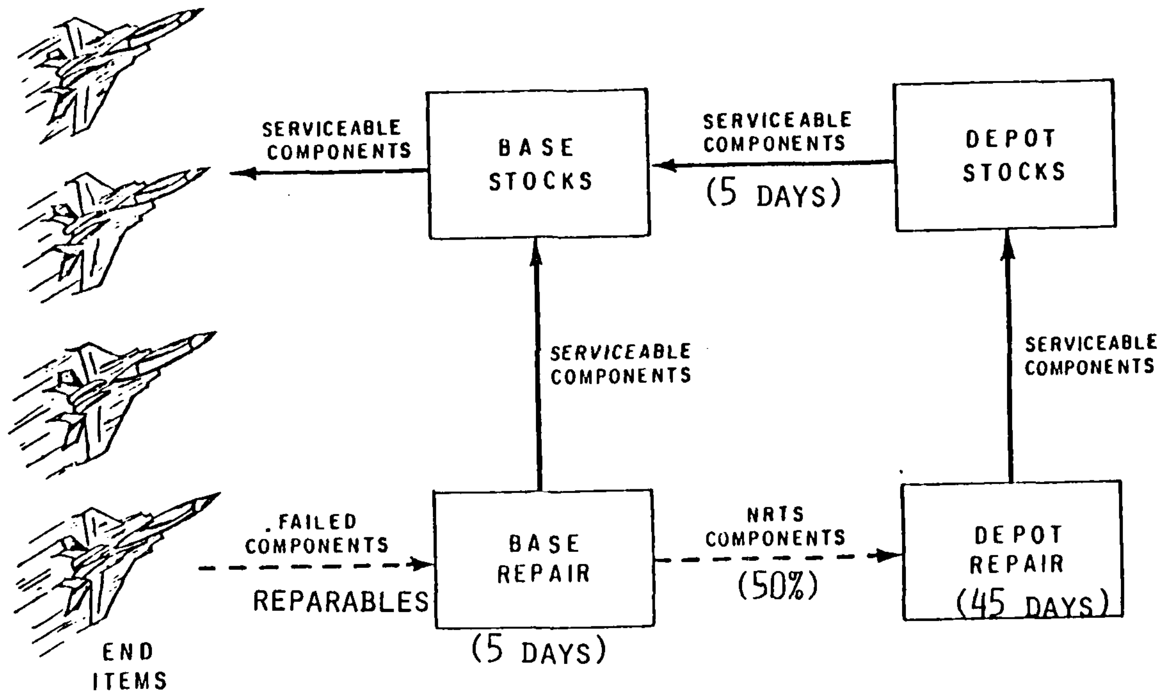


FIGURE 1-2

FLOW OF COMPONENTS



CONTINUOUS REVIEW INVENTORY POLICY

The expected number of each component in resupply, i.e., the item pipeline quantity, is 8.25. By resupply we mean in base repair, depot repair, or transit.

The relationship between the end-item availability and spares investment cost computed by the availability model is depicted graphically in Figure 1-3. This curve is typical of many such availability-vs.-cost curves despite the simplistic character of this example.

A stockage posture of special interest is that of buying eight of each component. Such a posture emulates, to some extent, Standard Initial Provisioning (SIP), which consists of provisioning a pipeline's worth of spares at each below-depot echelon and a pipeline's worth plus a three-month procurement cycle/safety level at the depot for all components that are demand-supported. For our simple example, what we mean by "SIP" is buying a pipeline quantity of each item with no provision for safety stock. Note that SIP does not take unit cost into account. For this case, we compute the availability associated with the optimal distribution of the items among the depot and bases. In Figure 1-3, the point designated "SIP" represents the availability and cost that would result from buying a pipeline's worth (8) of each item. The cost is $4,092,000; the resulting availability is 84.6 percent. This posture can readily be compared to the availability-vs.-cost curve computed by the availability model; however, two points on that curve are of special interest for comparative purposes, one where the availability is the same as for the SIP posture, the other where the cost is the same. The comparison is made directly in Table 1-3.

As this example shows, for the same budget of $4,092,000, an optimal posture yields an increase in availability from 0.846 to 0.942, an average of

FIGURE 1-3

AVAILABILITY VS. COST

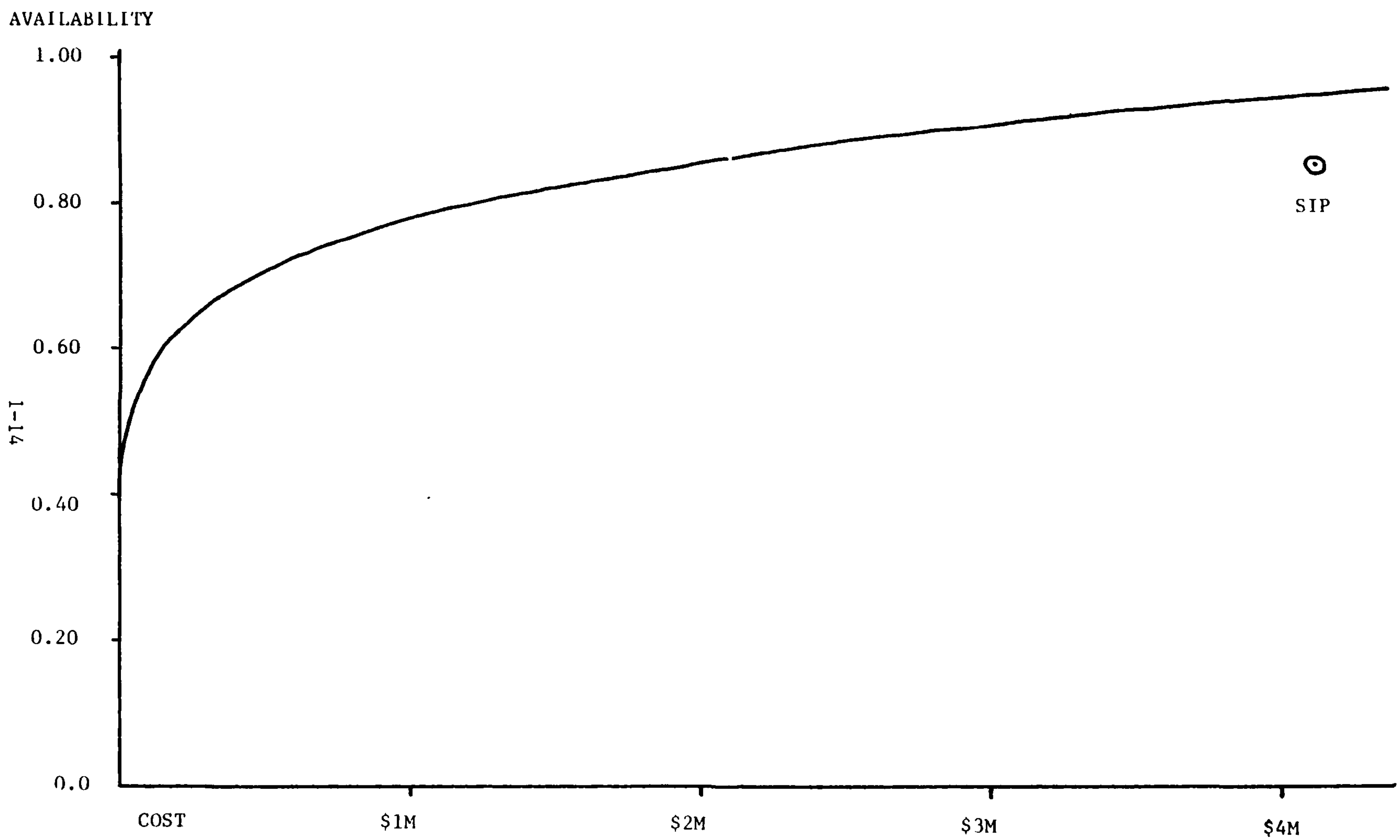


TABLE 1-3

"SIP" VS. OPTIMIZATION

ITEM	UNIT COST	"SIP"	OPTIMIZATION	
1	500	8	20	19
2	1,000	8	20	17
3	2,000	8	19	17
4	4,000	8	16	16
5	8,000	8	15	14
6	16,000	8	14	13
7	32,000	8	13	11
8	64,000	8	12	9
9	128,000	8	9	4
10	256,000	8	5	0
	COST $	4,092,000	4,092,000	1,884,500
	AVAIL %	84.6	94.2	84.6

8.64 more available end items; furthermore, an optimal posture will produce 0.846 availability for $1,884,500, less than half the cost of the SIP posture.

One can easily see from this straightforward comparison the superiority of an optimized posture; however, the computations underlying this example assume that all item and system characteristics are known with certainty and that steady-state conditions apply.

DEALING WITH UNCERTAINTY

In our example, the pooled base daily demand rate of each of the 10 items was 0.3. Our computations of availability assumed that this intensity of demand was a known constant and that demands were generated randomly over time with this specified intensity, i.e., the number of demands observed in a time period of arbitrary length, say t days, followed a Poisson distribution with parameter 0.3t.

Suppose, now, we are uncertain about that demand rate because item and weapon-system characteristics are not fully known and we are faced with unreliable data. We will characterize our uncertainty about the demand rate by modelling it as a random variable with the probability density function shown in Figure 1-4. The probability distribution we have chosen to describe our uncertainty about the demand rate is known as a gamma distribution. We will refer to it again by name.

We now recompute the availability-vs.-cost curve taking explicit account of our uncertainty about demand. The result is shown in Figure 1-5. For comparative purposes, the curve of Figure 1-3 is reproduced in Figure 1-5 as a dashed line.

The relationship between these two curves can tell us something about the worth of reliable demand estimates because the more uncertainty we have about the demand rate, the more we need to invest if we expect to achieve a *specified level of availability.* In this simple example, if we specified an expected availability rate of 90 percent, it would require about $4 million in the face of our uncertainty but only about $3 million if the demand rate were known. Thus, the expected value of perfect information about the demand rate in this particular case is about $1 million. Given the right kind of representation of uncertainty about item characteristics, it is feasible to compute the expected value of additional operational test and evaluation (OT&E) of specified length or of additional hours or miles of end-item operation.

It is interesting to examine two particular points on this availability -vs.-cost curve, again for comparative purposes, the one with an availability equal to the SIP availability (0.846) and the one with the same investment, $4,092,000. These two new stockage postures are shown in Table 1-4 with the stockage postures examined previously.

FIGURE 1-4

A MODEL OF UNCERTAINTY

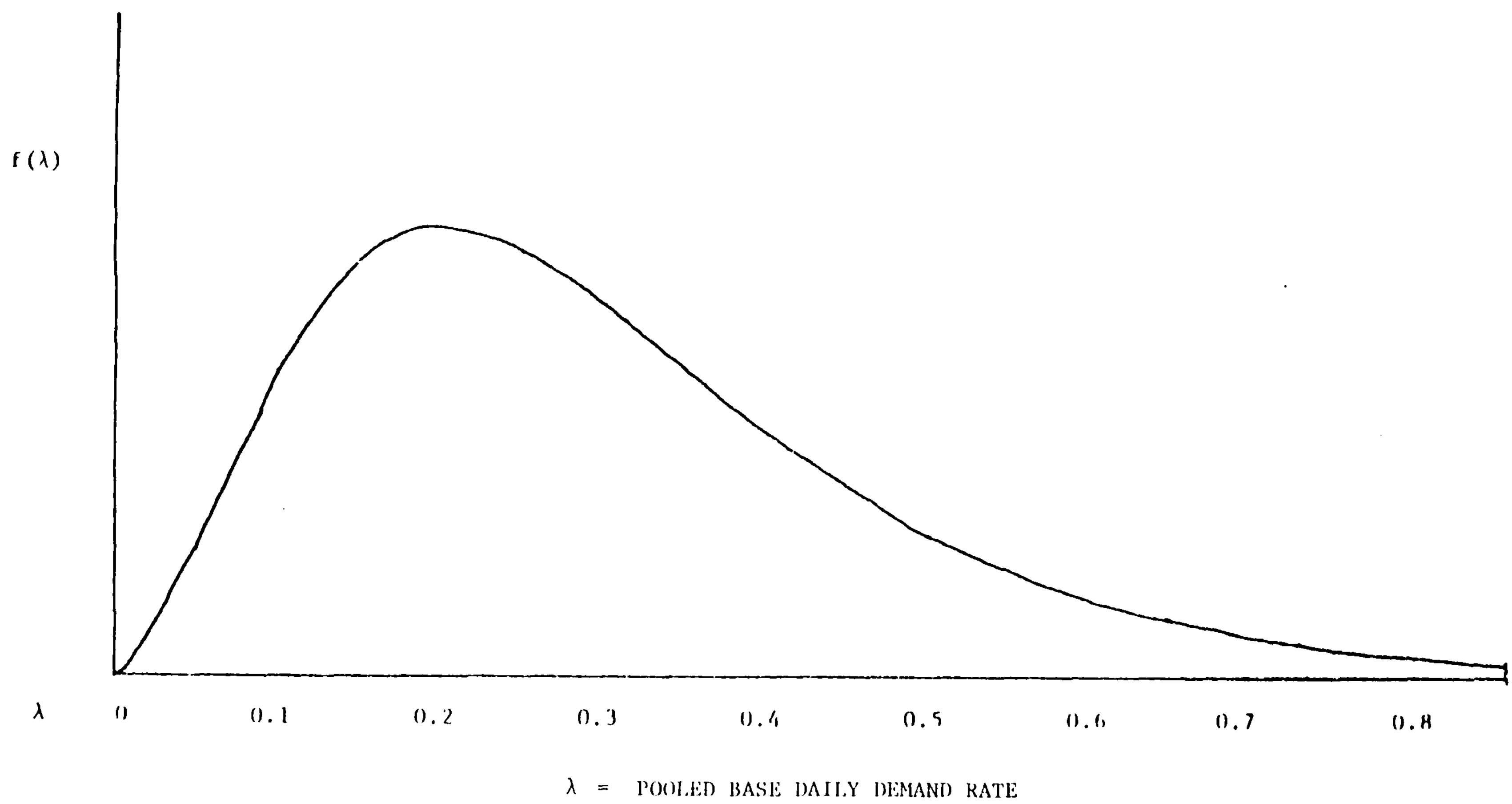


FIGURE 1-5

AVAILABILITY VS. COST WHEN
THE DEMAND RATE IS A RANDOM VARIABLE

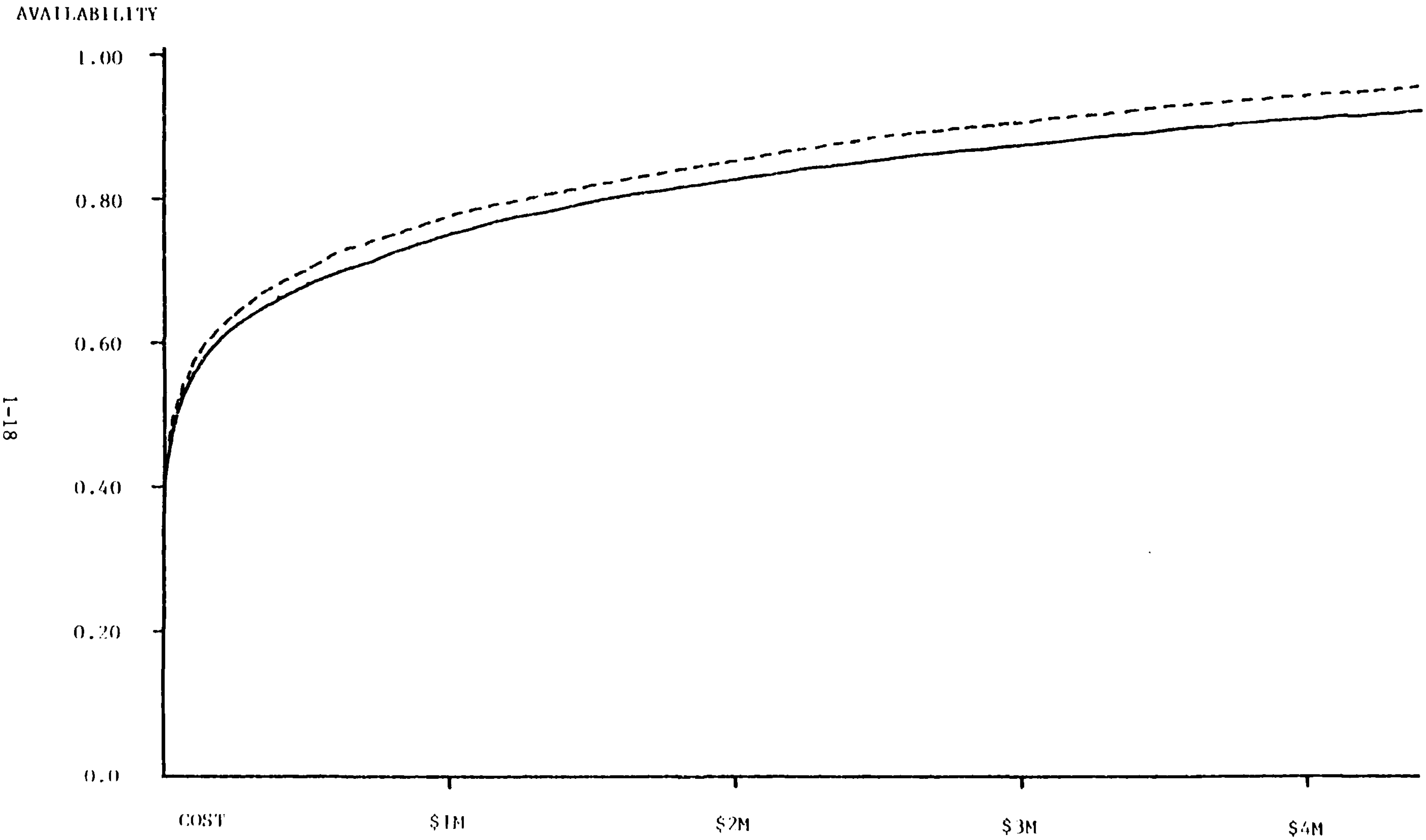


TABLE 1-4. SIP VS ALTERNATIVE POSTURES

ITEM	UNIT COST ($000)	QUANTITIES BY POSTURE				
		SIP	A	B	C	D
1	0.5	8	19	20	33	34
2	1.0	8	17	20	30	31
3	2.0	8	17	19	27	28
4	4.0	8	16	16	24	25
5	8.0	8	14	15	21	22
6	16.0	8	13	14	18	20
7	32.0	8	11	13	15	16
8	64.0	8	9	12	10	13
9	128.0	8	4	9	6	8
10	256.0	8	0	5	0	4
COST($)		4,092,000	1,884,500	4,092,000	2,540,500	4,092,000
ESTIMATED AVAILABILITY (%)		84.6	84.6	94.2	84.6	90.3
ACTUAL AVAILABILITY (%)		76.2	80.0	88.6	84.6	90.3
ACTUAL FILL RATE (%)		40.9	61.9	71.8	73.9	78.2
ACTUAL INVENTORY TURNOVER RATE (ANNUAL)		13.69	9.13	7.66	5.95	5.45

Table 1-4 contains, for each stockage posture, two availability rates. The availability rates identified as "Estimated Availability" for the SIP posture and postures A and B were computed as though the demand rates were known constants. For policies C and D they were computed as though the demand rates were random variables that follow the gamma distribution of Figure 1-4.

The availability rates identified as "Actual Availability" are the expected availability rates that result from selecting randomly a demand rate for each component from that gamma distribution. In other words, they are the expected availability rates that eventuate in the face of uncertainty. The same is true of "Actual Fill Rate" and "Actual Inventory Turnover Rate."

It is important to note that the SIP posture is the most vulnerable to uncertainty of those examined here.

FILL RATES, INVENTORY TURNOVER RATES, AND "EXCESSES"

In addition to the availability rates and costs of the five stockage postures described in Table 1-4, the fill rates and inventory turnover rates of the postures are also shown. Note that, in general, the more effective the stockage posture (i.e., the higher its availability rate), the higher its fill rate and the lower its inventory turnover rate. That the fill rate should tend to increase as end-item availability increases is, perhaps, intuitively obvious since the more effective policies give up only a few of the highest-cost items in return for much greater protection in many more line items. That the inventory turnover rate should tend to decrease as availability increases is probably just as obvious for the same reasons; however, what we mean by inventory turnover rate shouldn't be obvious at all since it is a measure that is usually applied to inventory systems for non-recoverable items, not recoverables. Inventory turnover rate is typically defined as <u>sales revenue</u> divided by <u>inventory dollar value</u>. Sales revenue is computed for some arbitrary period of time, say 12 months.

The inventory turnover rate is intended to measure the "efficiency" of an inventory system. It is a measure that is often of interest to persons with experience in supply management. It is not a measure that is popularly used in the DoD except for consumable or perishable inventories. It is oriented toward the inventory management system rather than the reason that the inventory management system exists, i.e., supply support of the end items. Such measures for recoverable inventories should be of academic interest at best; if they ever induce any management actions or policy formulation, such actions or policies are probably counter-productive to cost-effective weapon-system support.

Clearly, the classical definition of inventory turnover rate does not apply to recoverable items because, in the case of recoverables, there is no sales revenue. The inventory dollar value is also conceptually unclear since a substantial proportion of the inventory is in resupply, i.e., base repair, depot repair, or in shipment to or from the base or depot. The definition of inventory turnover rate used here is <u>total units demanded per year</u> divided by <u>total stock level</u>.

Another very troublesome concept in supply management is that of <u>excesses</u>. Policies that cause disposal action to be taken on assets that are declared to be excess may be counterproductive if they induce disposal actions that are followed by later procurement actions on the same line items. Policies regarding excesses are typically demand-based, e.g., disposal action might be mandatory on any assets in a certain category that have not experienced a demand in the last 180 days. Such arbitrary rules tend to militate against adequate range in an inventory; therefore, they may diminish the cost-effectiveness of the inventory system. Such policies should take a <u>system</u> view rather than an <u>item</u> view. One cannot judge what is excess and

what is not on an item-by-item basis. The most cost-effective stockage posture among the several shown in Table 1-4, i.e., posture D, depends for its effectiveness on being able to stock more of the first eight line items than the SIP posture, giving up in return a few of the highest-cost line items. Having decided upon posture D and implemented it, one can not later decide to declare as excess all assets above, for example, twice the pipeline. The stockage posture is an integral whole. Its worth must be judged accordingly. Its turnover rate may be lower than some arbitrary notion of what the turnover rate should be and, from some points of view, some of the less expensive assets may appear to be excess to someone's arbitrary notion of requirements. What is fundamentally important here is that the performance of the stockage posture should not be measured in terms of inventory management "efficiency" when the very reason one invests in spares in the first place is weapon-system availability.

WHOLESALE VS. RETAIL: A LESSON ON TOGETHERNESS

For every stockage posture examined so far, the availability has been computed based on the stock-level distribution among the depot and bases that minimized expected base-level backorders, i.e., that maximized end-item availability. In order to provide some basis for at least an intuitive understanding of the importance of distribution we present several alternative distributions for the simplistic weapon system we have been examining where we have a total of eight of each component, i.e., the posture that emulates a SIP posture.

We first discuss, for illustrative purposes, the cases where all of the stock is put at a single echelon. In the first case, all of the stock is allocated to the depot, in the second case all to the bases. (See Figures 1-6 and 1-7.)

FIGURE 1-6

ALLOCATION TO THE DEPOT

Expected Backorders = 2.05

Availability = 79.5%

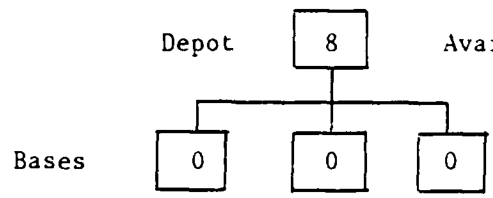
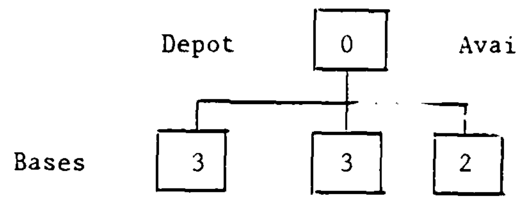


FIGURE 1-7

ALLOCATION TO THE BASES

Expected Backorders = 2.12

Availability = 78.8%



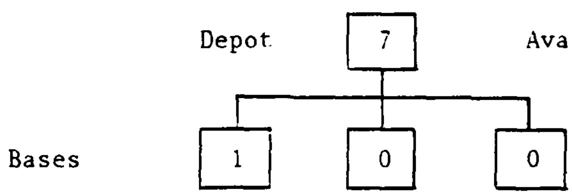
Both of these alternatives yield roughly 79 percent availability. Another alternative is represented by partitioning the stock levels in the same proportion as the depot and base pipeline quantities. In our example, the item pipeline is 8.25; that consists of a depot segment of 6.75 and a base segment of 1.5. The closest approximation to this partitioning, a depot stock level of seven and a base stock level of one, is shown in Figure 1-8.

FIGURE 1-8

ALLOCATION BY PIPELINES

Expected Backorders = 1.86

Availability = 81.2%



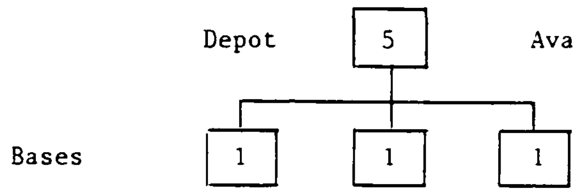
This distribution is better than either of the other two; however, it can be improved significantly. If one examines every possible allocation of the stock levels, the following optimal distribution emerges (see Figure 1-9).

FIGURE 1-9

OPTIMAL ALLOCATION

Expected Backorders = 1.50

Availability = 84.6%



Thus, it is possible, in this case, to gain another 3.4 percent availability (3.06 end items, on the average) without investing a single dollar in stock, simply by being smarter about distribution.

CONCLUSIONS

Four fundamentally important conclusions can be drawn from this analysis, however simplistic the example. They are:

1. Availability models provide a way to achieve specified levels of availability at substantially less cost than item-oriented approaches; thus, they provide the policy maker with the opportunity to minimize spares investments while still providing effective weapon-system support.

2. Cost-effective stockage postures cannot be based on demand rates alone; other item characteristics must be considered.

3. The policy maker must view the various echelons as parts of an integrated system. One should not make policy for the "wholesale" level independent of the "retail" level.

4. Stockage postures computed by availability models are less vulnerable to uncertainty than are stockage postures computed by item-oriented techniques.

PROBLEMS AND COUNTERARGUMENTS

We believe that the evidence presented and discussed in this chapter and the chapters that follow clearly and persuasively supports the use of availability models in initial provisioning; however, the application of mathematical models is never free of problems. Indeed, from the points of view of some experienced and reasonable persons, item-oriented techniques seem preferable to availability models. Those points of view need to be understood because the arguments that emanate from them are not without merit.

Cannibalization

All of the widely used availability models depend on the simplifying assumption of no cannibalization; yet, cannibalization has a significant effect on the performance of a stockage posture. The assumption is important to the mathematical tractability of the model but results in underestimating the performance of the computed stockage posture. The amount of improvement resulting from cannibalization is not uniform across different stockage postures. To illustrate this fact, we again refer to our simplistic, 10-component weapon system. Table 1-5 shows several measures of performance for three of the stockage postures previously discussed and reflects two additional stockage postures, E and F, that are optimal in the face of cannibalization.[1] Posture E is optimized for Poisson demand and posture F for demand where the mean demand rate follows the gamma distribution of Figure 1-4.

[1] We cannot show that these postures are optimal; however, an extensive search of alternative postures could not improve upon those shown.

TABLE 1-5. SIP VS ALTERNATIVE POSTURES
IN THE FACE OF CANNIBALIZATION

ITEM	UNIT COST ($000)	SIP	B	D	E	F
1	0.5	8	20	34	20	32
2	1	8	20	31	18	30
3	2	8	19	28	16	27
4	4	8	16	25	16	24
5	8	8	15	22	14	21
6	16	8	14	20	13	19
7	32	8	13	16	12	15
8	64	8	12	13	11	12
9	128	8	9	8	8	9
10	256	8	5	4	6	4
<u>WITH POISSON DEMAND:</u>						
AVAILABILITY WITHOUT CANNIBALIZATION		84.6	<u>94.2</u>	93.3	94.1	93.6
AVAILABILITY WITH CANNIBALIZATION		93.1	95.3	94.5	<u>95.5</u>	94.6
FILL RATE		30.2	76.4	79.7	74.2	79.6
<u>WITH GAMMA-DISTRIBUTED MEAN DEMAND RATE:</u>						
AVAILABILITY WITHOUT CANNIBALIZATION		76.2	88.6	<u>90.3</u>	87.9	90.2
AVAILABILITY WITH CANNIBALIZATION		87.2	91.7	92.2	91.4	<u>92.3</u>
FILL RATE		40.9	71.8	78.2	71.7	77.7
INVENTORY TURNOVER RATE		13.7	7.66	5.45	8.17	5.67

TOTAL COST OF EACH POLICY IS $4,092,000.

Policies A and C have been excluded for the sake of clarity since they are lower-cost postures than the five postures shown.

Several important observations can be made about these stockage postures. In the face of Poisson demand, the performance of the SIP posture

is the most improved by cannibalization; its availability rate improves from 84.6 to 93.1 percent. Note, however, that it is still dominated by every other posture. Posture E, which is optimized for cannibalization with Poisson demand, yields an expected 0.71 more available end items than the SIP posture. Note, too, that in the face of uncertainty, i.e., when the mean demand rate follows the gamma distribution of Figure 1-4, the performance of the SIP posture suffers the greatest degradation of all the postures shown. In this case, posture F yields an expected 1.51 more available end items than the SIP posture.

Another fundamentally important observation is that, in the face of uncertain demand in an environment in which cannibalization occurs, the performances of postures B, D, E, and F are very similar, there being only 0.9 percent difference in end-item availability between the best and the worst.

These results are based on the assumption of no lateral resupply. Lateral resupply also acts to improve the performance of a stockage posture but, again for reasons of mathematical tractability, its effects can only be estimated.

The Validation Problem

Another important issue with respect to the application of an availability model is the extent to which the numerical values produced by the model have been validated by empirical observations. The LMI Aircraft Availability Model, a model of the Air Force's two-echelon recoverable item management system, is built around the same fundamental logic as the model used to support the computations shown earlier in this chapter. The LMI model was extensively validated by an interdisciplinary team working for almost a year with data from the Air Force Maintenance Data Collection System and the AFLC D165A Worldwide NORS Incident Reporting System. The validation consisted of

three separate efforts. The first examined the accuracy of the model's computations of expected backorders; the second examined the accuracy of the mathematical model that computes weapon-system availability as a function of the expected backorders for all of the system's components; the third examined the estimating accuracy of the entire system, including its input data base.

The conclusions reached in this effort were (1) that the error associated with relatively high availability estimates was smaller than with lower availability estimates and (2) that a simple linear correction of the form $A' = a + bA$ produced revised estimates that were remarkably accurate over a wide range of weapon systems (where A is the computed availability, A' is the corrected estimate, and a and b are positive constants whose sum is one). This extensive validation effort and its outcome led the Air Force to adopt the model as an integral part of its Logistics Capability Measurement System.

Of special interest here is the fact that the results of the LMI validation are, in part, extendable to some of the assumptions implicit in the algebra of certain other multi-echelon inventory models. Specific attention was given to assumptions about the probability distributions of demands and backorders, the ratio of the variance to the mean of the backorder distribution, and the requirements computations made by a model that maximizes availability viz-a-viz a model that minimizes expected backorders. Thus, our observations, conclusions, and recommendations here are based in part on our confidence in the mathematical models involved.

The Data Problem

Among the most common counterarguments to the use of availability models in initial provisioning is that they are essentially inappropriate for use without refined and reliable data; in other words, the argument goes, "Who

needs a fancy mathematical model when the only failure rates and costs available are, at best, just someone's estimates? Garbage in, garbage out! If you can't trust the inputs to a model, how can you trust the outputs?"

Perhaps the most important conclusion about data that can be drawn from this study is that, the more uncertain one is about the true values of component characteristics, the more one needs an availability model to compute stockage postures and availability-vs.-cost curves. In the face of uncertainty, the most cost-effective stockage posture lies even further away from an item-oriented posture than does a posture computed by an availability model that assumes known demand. Furthermore, the stockage posture that is built on the explicit assumption of uncertainty is the most immune to error, i.e., it is the least vulnerable with respect to its ability to deliver end-item availability in an environment of uncertainty. This characteristic is clearly evident not only in the simple, ten-component weapon system examined in this chapter but also in each of the several Army systems examined in the next two chapters.

Operational-Test and Evaluation (OT&E) Data

A frequently encountered question about data to support an availability model is the extent to which OT&E data should be used to determine spares requirements. There is a well known, well developed technique for using data to modify prior estimates of item characteristics called Bayesian learning. Bayesian learning constitutes a way for pooling judgments about components with actual observations in a way that assigns the optimal weight to each, i.e., it weights judgments and observations in a way that is consistent with the degree of uncertainty in the judgments.

All that we know about Bayesian learning suggests its suitability for application to the initial provisioning problem because, typically, OT&E

data alone are insufficient to determine component characteristics; yet, it is only reasonable that, at the time the provisioning is done, the requirements computation be based on as much information as is then available. Thus, we strongly believe that the input data to an availability model being used for initial provisioning should reflect both whatever judgmental estimates are available and whatever empirical data are available, and that those two sources of information about component characteristics be pooled optimally.

The Obsolescence Problem

An availability model tends to deliver stockage postures consisting of fewer high-cost items and more low-cost items; however, in balance, the postures in general reflect a greater total quantity of items than an item-oriented posture. Therefore, if every line item is equally likely to incur costs of design changes and the costs of all of those design changes are equal, then an "optimized" stockage posture is not, in fact, optimal at all because its expected cost of design changes will clearly be higher than an item-oriented posture's. However, if the higher-cost items are more likely to incur the costs of design changes than the lower-cost items or if the costs of the changes tend to be greater on the higher-cost items, then it is not clear which posture ("optimized" or item-oriented) would have the higher obsolescence cost. The solution to the problem of taking explicit account of obsolescence costs is to adopt the concept of basing the computation of a stockage posture on expected component cost rather than simply on unit prices where the expectation accounts for the risk of obsolescence. The method has yet to be demonstrated.

Mission Criticality

A possible hedge against uncertainty lies in initially provisioning mission-critical items only. Once all the components of an end item have been

characterized as either critical or noncritical, the technical problem of taking mission criticality into explicit account in the computation of the stockage posture is trivial. The problem is solely one of policy.

Factors and Strategies That Mitigate Uncertainty

There are several factors in many initial provisioning scenarios that operate to mitigate uncertainty, i.e., they tend to act in the direction of limiting the risk of over-investment. For example:

1. The sheer weight of numbers in some programs is very forgiving in the sense that it is difficult to overbuy in an ultimate sense when one is provisioning for the first 100 end items and 10,000 will be produced or for the first year of ten years' production. (Program size alone does not, however, mitigate the uncertainty about design changes.)
2. If the behavior of component unit prices is to increase substantially over the early life of a system, as we have observed in some systems, then spares budgets will tend to result in less spares investment. Thus, the tendency toward price increases provides a sort of built-in budgetary constraint.
3. If failure rate estimates also tend to increase substantially over the early life of a system, then the effect of failure rate increases also tends to induce lower spares budgets.

In addition to such factors, one can also establish lower availability goals early in a weapon system's life as a strategy to hedge against uncertainty. The availability model is a powerful tool for understanding better what the tradeoffs between availability and cost really are because it makes those tradeoffs explicit. Furthermore, to the extent that an availability model delivers a stockage posture that is less vulnerable to uncertainty

than the posture computed by an item-oriented technique, it is a more cost-effective policy, i.e., it will achieve a specified level of availability at substantially less cost than the item-oriented approach.

Thus, there are several factors operating in the initial provisioning environment that tend to militate against overinvestment. The effects of those factors can be enhanced by the intelligent application of availability models.

2. A METHODOLOGICAL DEMONSTRATION OF AN AVAILABILITY MODEL APPLIED TO FOUR ARMY WEAPON SYSTEMS

OVERVIEW

In this chapter we extend our discussion of the use of availability models in initial provisioning and examine the application of one such model to four new Army weapon systems, the XM-1 tank, the Patriot missile, the Firefinder radar, and the Ground Laser Locator Designator (GLLD). Currently, the two most widely used methods for computing initial provisioning budgets and stockage requirements in the Army are the Standard Initial Provisioning (SIP) method and an availability model embodied in the SESAME (Standard ERPSL Spares Allocation Methodology) Model, developed by the Army's Inventory Research Office. As explained previously, SIP is not synonymous with the item-oriented computations described in DoDI 4140.42. The DoDI prescribes procedures for provisioning demand-based items and non-demand-based items. The non-demand-based items are further categorized as numerical-stockage-objective (NSO) items and insurance-type items. The financial base prescribed by DoDI 4140.42 is computed as the total investment cost for all of these categories of items. SIP applies only to the demand-based category.

The provisioning computations discussed here were performed using SESAME. The SESAME model may be used in any of three modes. These include (1) SIP, (2) SIP plus ERPSL (Essential Repair Parts Stockage List), and (3) ERPSL with SIP minimum. Two constraints are also available in SESAME to be used with either of the two ERPSL modes, (1) the One-Each Rule and (2) the Retail Inventory Management and Stockage Policy (RIMSTOP). Each of these is explained below.

Standard Initial Provisioning

The SIP mode of SESAME may be used to compute both wholesale and retail stockage requirements. In the SIP mode, stockage requirements are computed one component at a time.

For retail stockage requirements computation in the SIP mode of SESAME, the annual demands at each claimant for each item are computed and compared to a Retail Stockage Criterion (RSC). This criterion is supplied as an input to the model. For most weapon systems, the RSC is set at six demands per end item per year. If the annual demands for an item at a claimant are greater than or equal to the RSC, then the quantity stocked will be equal to the repair pipeline quantity plus the order-and-ship time (OST) pipeline quantity or one--whichever is greater. If the annual demands for an item at a claimant number less than the RSC, the quantity stocked will be equal to the repair pipeline quantity plus the OST pipeline quantity--rounded to the nearest integer. In other words, the SIP method as implemented in SESAME places a pipeline's worth of spares at each retail claimant qualified under the retail stockage criterion.

For the wholesale computation, the model computes both the wholesale provisioning requirement and the total replenishment requirement. The wholesale provisioning requirement of initial spares is equal to the quantity of spares required to fill the depot repair pipeline for the number of weapon systems being deployed in the provisioning period. The replenishment requirement of spares is equal to the quantity required to replace items lost or condemned during the period of computation, usually one year.

In the SESAME model the wholesale computation is done separately from the retail computation; therefore, the weapon system deployment configuration and the amount and distribution of retail spares have no effect on

the quantity of spares at the depot. This independent computation of wholesale and retail provisioning in itself limits the ability to optimize initial spares stockage for the weapon system.

Essential Repair Parts Stockage List (ERPSL)

For the retail stockage computation in the ERPSL mode, the SESAME model first places stock at each claimant equal to that computed in the SIP mode, then evaluates the cost-effectiveness of increasing stockage. We will refer to this methodology as "SIP MIN ERPSL" since the minimum stockage for any item is the level computed by the SIP method. The ERPSL program effectively computes, for each item, all the possible distributions of the item for each quantity within the retail supply structure up to the level where adding more spares would no longer be cost-effective. The cost-effectiveness cutoff is determined by the cost of a backorder which is supplied as an input to the model. The resulting overall retail stockage for all items will then yield the lowest possible supply response time and highest availability for the weapon system, given the SIP stockage posture as a starting point. SIP MIN ERPSL is the provisioning method being used for the XM-1 tank system.

One must remember that since the initial baseline SIP quantities that provide the starting point of the stockage computation in this mode were not optimized, the overall stockage cannot be considered optimal.

A simple modification to the SESAME model permits one to compute the ERPSL optimized stockage with all initial item quantities set to zero. We refer to this mode as "Zero Base ERPSL". Since the ERPSL stockage rules are intended to provide the most cost-effective stockage position, this approach will produce a more effective stockage policy at lower budget levels than any of the computational approaches currently embodied in the SESAME model.

Under the "SIP plus ERPSL" mode of SESAME, the initial spares stockage requirement is first calculated under SIP rules and then an ERPSL requirement is computed for only those items which did not qualify for SIP stockage at any retail claimant. With this methodology, an item may be stocked at the retail level under SIP demand rules or ERPSL rules but not both. The ERPSL stockage requirement for each item is computed using the same logic as discussed for the SIP MIN ERPSL mode. Since the SIP plus ERPSL mode can only perform ERPSL computations for those few items that have no retail stockage under SIP, the utility of this mode is negligible.

Once all the item quantities and distributions have been determined under any of the ERPSL modes, the model will then compute the total stockage cost and availability (A_s). This computation gives a single A_s/cost point for the computed stockage posture. By running the program several times for different levels of backorder cost, a series of A_s/cost points may be plotted which describe an A_s/cost curve for the weapon system.

Retail Inventory Management and Stockage Policy

The Retail Inventory Management and Stockage Policy (RIMSTOP) may be used with any of the aforementioned ERPSL modes. As implemented in the SESAME model, the RIMSTOP functions as a constraint on the ERPSL computation by limiting stockage of an item to only one additional retail echelon beyond that permitted under the SIP rules. For example, if an item was not stocked at any retail echelon under the SIP rules, as in Zero Base ERPSL, it could be stocked at only one retail echelon by the ERPSL method under the RIMSTOP constraint. Without RIMSTOP, however, it could have been ERPSL-stocked at any or all of the retail echelons. Additionally, in a three echelon retail configuration, if an item were stocked at only one retail echelon under the SIP rules, it could be ERPSL-stocked at one of the remaining two echelons, but not both,

under the RIMSTOP constraint. Any policy that arbitrarily constrains the distribution of stock results in reduced cost-effectiveness. This is clearly demonstrated when the RIMSTOP constraint of SESAME is applied to the Zero Base ERPSL methodology.

We modified the SIP mode of SESAME to limit the SIP baseline quantity to a maximum quantity of one per claimant. This permitted us to evaluate the RIMSTOP constraint for a stockage position between the Zero Base ERPSL and the SIP MIN ERPSL. We have designated this method as "SIP (ONE MAX)". It is run in the same way as SIP MIN ERPSL. The suboptimization of the SIP baseline stockage using SIP (ONE MAX) ERPSL is substantially less than in the SIP MIN ERPSL mode. The SIP (ONE MAX) ERPSL mode was created for the sole purpose of helping to evaluate the RIMSTOP constraint and is not suggested for use as a stockage computation method for any weapon system.

One-Each Rule

The "One-Each Rule" is also a constraint placed on the Army ERPSL computations. This rule constrains ERPSL stockage to only one each of an item at any claimant which does not qualify to receive SIP stockage of that item. The One-Each Rule is used only in conjunction with RIMSTOP.

The SESAME model does not attempt to optimize stockage when used with the One-Each Rule and in this mode does not compute an availability. The model simply reduces the quantities of ERPSL items to one at those echelons where there had been no SIP stockage of the item.

COMPARISON OF METHODS

In this section we compare the performances of various combinations of the SIP and ERPSL methods, with and without the RIMSTOP and One-Each constraints, for each of the four selected weapon systems. The input data for these analyses are those Army Procurement Appropriation (APA) secondary item

planning factors used for the weapon system POM 82 computations. Performance is determined using the two primary criteria of cost and availability. Several other measures such as range of stockage and depth of stockage are also included for comparative evaluation. Cost-availability curves are plotted for each method for each weapon system.

XM-1 Tank

The initial provisioning A_s/cost curves (Fig. 2-1) for XM-1 display the performances of eight provisioning methods. Four of these are standard options in the current SESAME model: (1) Standard Initial Provisioning (SIP), (2) SIP plus ERPSL, (3) SIP MIN ERPSL and (4) SIP MIN ERPSL plus RIMSTOP. The remaining four methods result from modifications to the SESAME model in order to examine the results of higher levels of optimization on provisioning: (1) Zero Base ERPSL, (2) SIP (ONE MAX), (3) SIP (ONE MAX) ERPSL, and (4) SIP (ONE MAX) ERPSL plus RIMSTOP. These A_s/cost curves reflect only retail provisioning costs. The SIP-determined wholesale provisioning cost ($48,418,386) needs to be added to these retail costs to approximate the program's total FY82 requirement.

The provisioning performances of the SIP and Zero Base ERPSL methods were examined at the SIP-determined retail budget level. The SIP method achieved an availability of 67 percent for a total retail provisioning cost of $9,817,696. For approximately the same budget level as SIP, the Zero Base ERPSL method achieved an availability of 93 percent. (See Table 2-1). The range of items represents the number of lines (stock numbers) of the 162 APA secondary line items evaluated which were stocked at each of the retail echelons. It can be seen from Table 2-1 that the Zero Base ERPSL method stocked more lines at the organizational level (ORG) and direct-support level (DS) and fewer lines at general-support level (GS) than did the SIP method.

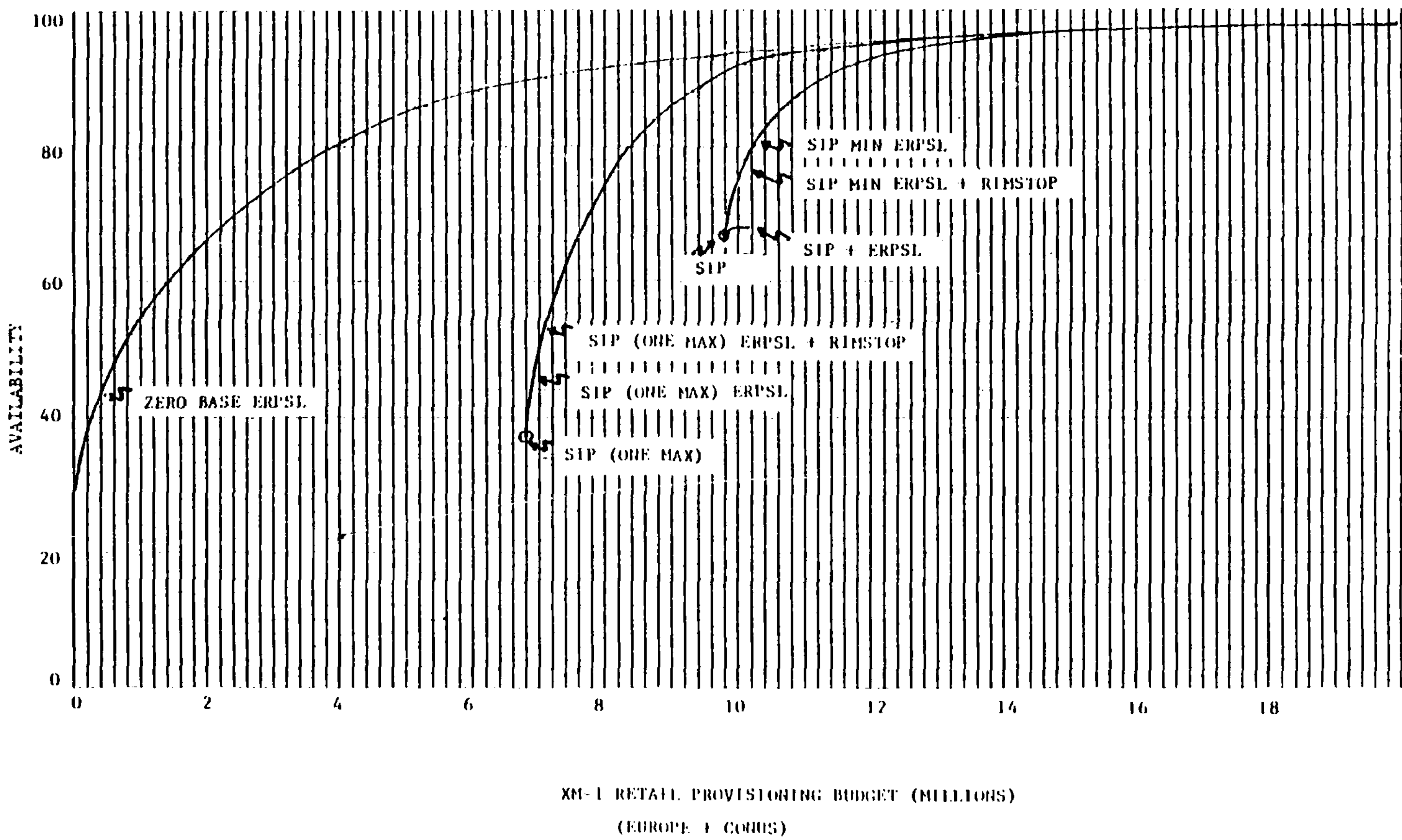


FIGURE 2-1. XM-1 As/COST CURVES

TABLE 2-1. SIP BUDGET LEVEL ANALYSIS, XM-1 TANK

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP	7	55	114	REF	REF	REF	$9,817,696	67
ZERO BASE ERPSL	13	83	108	108	50	4	$9,830,056	93

The depth of items represents the cumulative quantity of items stocked of a given line or stock number at the retail level. For the same budget level as SIP, the Zero Base ERPSL method provisioned higher quantities for 108 items, the same quantity for 50 items, and lower quantities for only four high-cost items. The entries under "DEPTH" in tables following Table 2-1 always reflect quantities relative to those provisioned by the first method listed in the table.

The provisioning performances of four methods were evaluated at the 80 percent availability level. These methods were: (1) SIP MIN ERPSL (the standard ERPSL mode of SESAME), (2) SIP MIN ERPSL with RIMSTOP, (3) SIP MIN ERPSL with the One-Each Rule, and (4) Zero Base ERPSL. The range of stockage for the first three methods was the same and yielded a retail budget requirement of approximately $10.3 million (see Table 2-[illegible]. The Zero Base ERPSL method achieved the same 80 percent availability for a retail provisioning budget of approximately $4 million, a savings of $6.3 million.

Clearly, for the XM-1 tank, the Zero Base ERPSL is significantly superior to the SIP methodology or any of the ERPSL methodologies currently available in SESAME.

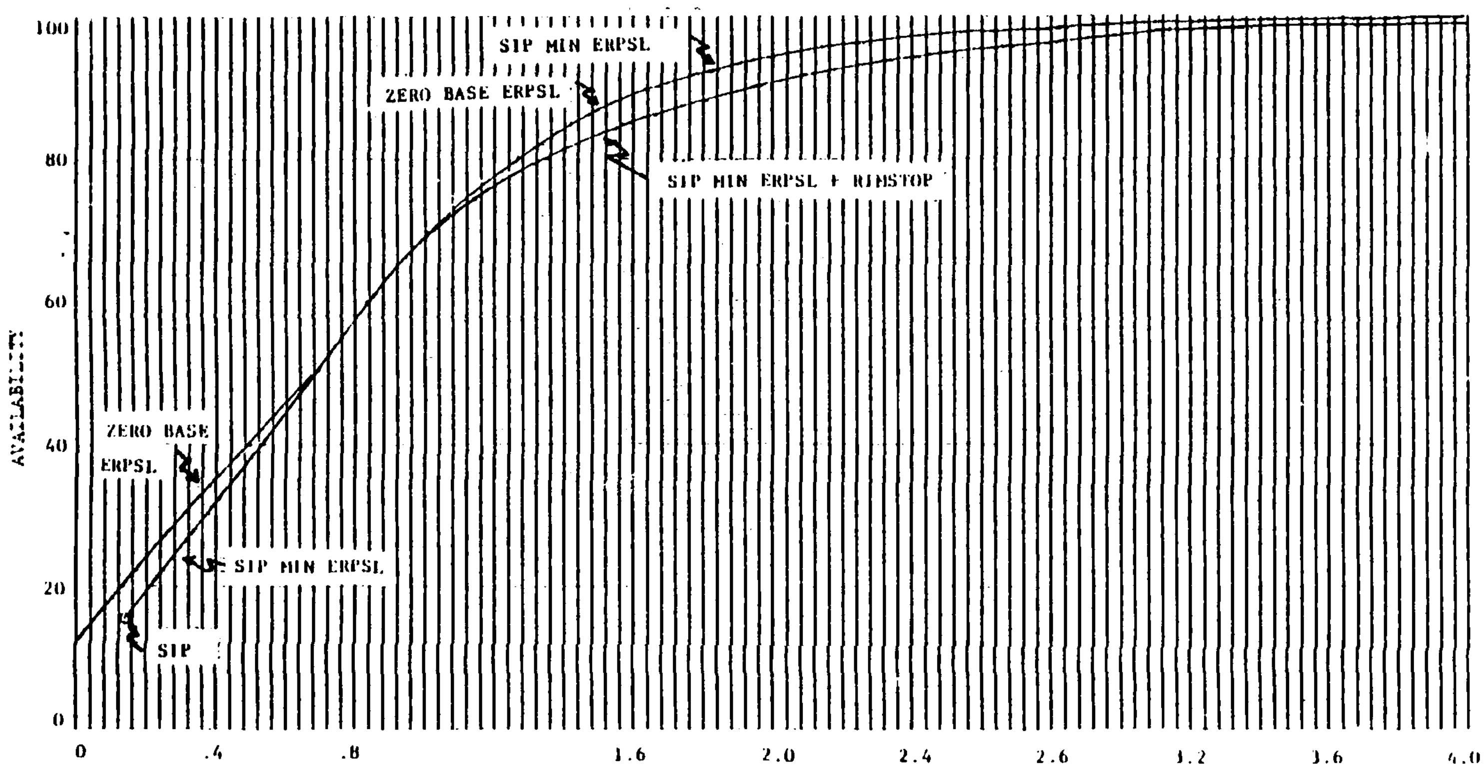
TABLE 2-2. 80 PERCENT AVAILABILITY LEVEL ANALYSIS, XM-1 TANK

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL	9	67	115	REF	REF	REF	$10,322,972	80
ERPSL with RIMSTOP	9	67	115	0	162	0	$10,322,972	80
ERPSL with ONE-EACH	9	67	115	0	160	2	$10,319,444	<80
ZERO BASE ERPSL	4	74	113	92	55	15	$3,987,065	80

Firefinder Radars

Separate initial provisioning analyses for Firefinder AN/TPQ-36 and AN/TPQ-37 have been performed because the SESAME model does not permit the simultaneous analysis of systems with commonality as does the Firefinder numerical stockage objective (NSO) model. Therefore, the results of these analyses are not directly comparable with the Firefinder provisioning requirements generated with the Firefinder model.

The A_s/cost curves for the Firefinder AN/TPQ-36 (Figure 2-2) and AN/TPQ-37 (Figure 2-3) display the performances of four provisioning methods, (1) SIP, (2) SIP MIN ERPSL, (3) SIP MIN ERPSL plus RIMSTOP, and (4) Zero Base ERPSL. These cost curves reflect only the retail provisioning costs. The SIP-determined wholesale provisioning costs ($4,404,079 for the AN/TPQ-36 and $3,731,369 for the AN/TPQ-37) need to be added to these retail costs to approximate the program's total FY82 requirement.



FIREFINDER AN/TPQ 36 RETAIL PROVISIONING BUDGET (MILLIONS)

FIGURE 2 2. FIREFINDER AN/TPQ 36 As/COST CURVES

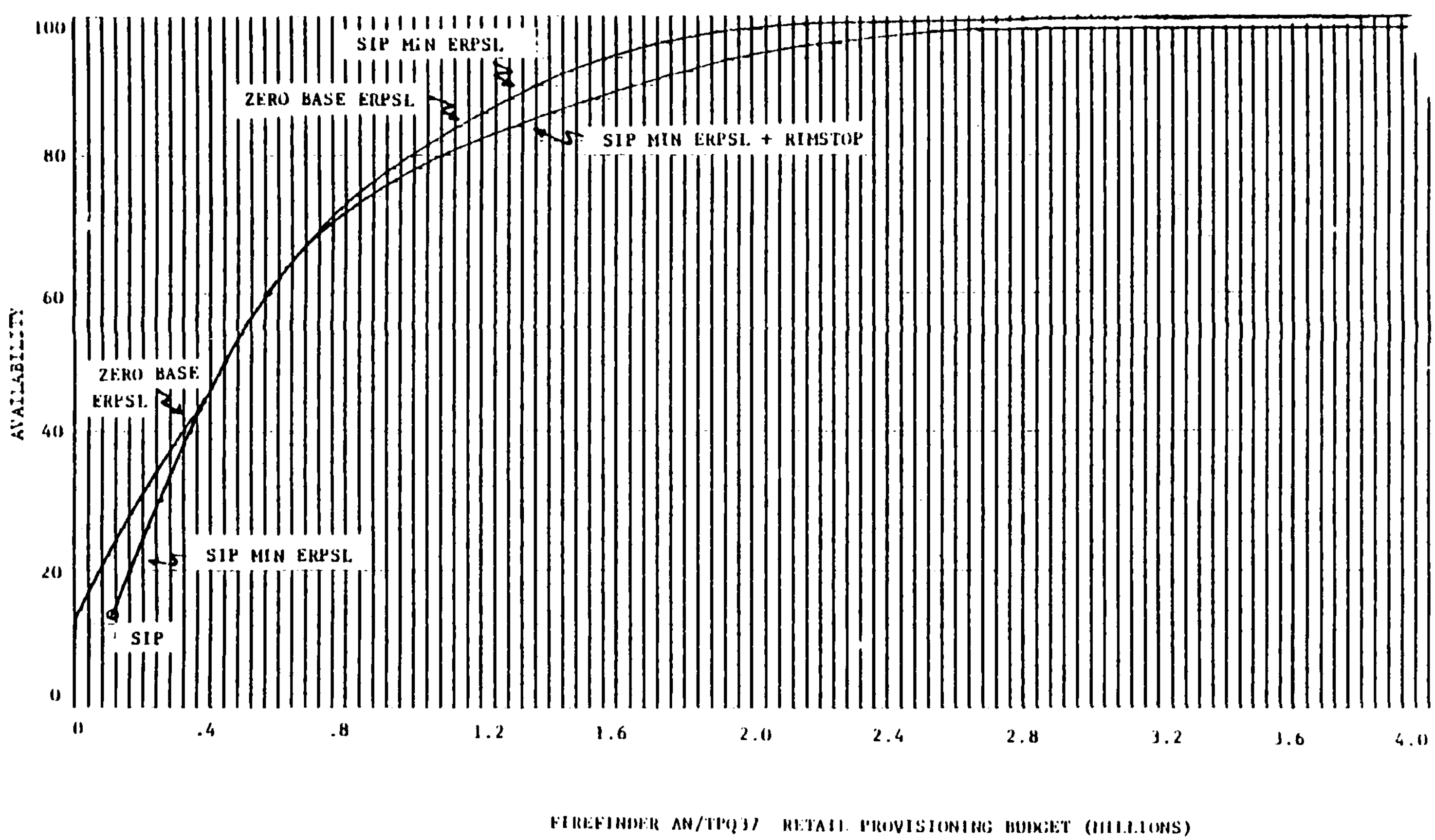


FIGURE 2-3. FIREFINDER AN/TPQ 37 As/COST CURVES

The provisioning performances of the SIP and Zero Base ERPSL methods were examined at the SIP determined retail budget level (see Tables 2-3 and 2-4). The SIP method achieved an availability of 14.3 percent for a retail provisioning cost of $146,373; for the same cost, the Zero Base ERPSL method achieved an availability of 19.1 percent.

TABLE 2-3. SIP BUDGET LEVEL ANALYSIS, AN/TPQ-36

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP	0	1	17	REF	REF	REF	$146,373	14.3
ZERO BASE ERPSL	4	2	80	79	66	8	$146,037	19.1

TABLE 2-4. SIP BUDGET LEVEL ANALYSIS, AN/TPQ-37

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP	0	0	10	REF	REF	REF	$135,548	13.4
ZERO BASE ERPSL	0	0	91	91	94	3	$135,268	22.6

The small availability difference between the two methods is attributable to the fact that so few items qualify for SIP stockage that only a small degree of suboptimization is caused by the SIP approach. However, the important observation here is that the SIP methodology produces an inadequate stockage and budget when applied to a low density, high reliability system and that an ERPSL or optimization method is essential for the weapon system to achieve an acceptable availability level.

The results for the AN/TPQ-37 were consistent with those for the AN/TPQ-36. As in the analyses for the previous weapon system, the provisioning performance of four methods was evaluated at a constant availability level. For the Firefinder radars the 97 percent availability level was used for the analysis. The range and depth characteristics of each method are shown in Tables 2-5 and 2-6.

TABLE 2-5. 97 PERCENT AVAILABILITY LEVEL ANALYSIS, AN/TPQ-36

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL	105	126	139	REF	REF	REF	$2,940,717	97
SIP MIN ERPSL + RIMSTOP	105	132	21	113	31	9	$3,330,337	97
SIP MIN ERPSL + ONE-EACH	105	132	21	2	20	131	$2,200,474	<97
ZERO BASE ERPSL	105	125	139	0	152	1	$2,937,249	97

TABLE 2-6. 97 PERCENT AVAILABILITY LEVEL ANALYSIS, AN/TPQ-37

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL	59	111	164	REF	REF	REF	$2,451,997	97
SIP MIN ERPSL + RIMSTOP	26	147	17	110	37	41	$2,966,171	97
SIP MIN ERPSL + ONE-EACH	26	146	17	5	37	146	$2,087,890	<97
ZERO BASE ERPSL	59	111	164	0	188	0	$2,451,997	97

For high reliability systems like Firefinder, the Zero Base ERPSL and the SIP MIN ERPSL methods perform almost identically. The RIMSTOP and One-Each Rule, however, degrade the cost-effectiveness of the ERPSL provisioning. The RIMSTOP constraint forces the ERPSL stockage of an item to be concentrated in fewer retail echelons than would be the case without RIMSTOP. For the Firefinder radars, the addition of the RIMSTOP to the SIP MIN ERPSL method forces the stockage forward in the retail system in order to concentrate it in fewer echelons. This results in a higher total retail quantity (depth) of most items and a higher provisioning cost in order to maintain the 97 percent availability.

The SESAME Model does not currently provide an availability computation for provisioning in the SIP MIN ERPSL plus One-Each mode. Because the One-Each constraint is applied only in conjunction with the RIMSTOP policy it is instructive to compare its effect on stockage depth and availability with the stockage provided in the RIMSTOP mode. (See Tables 2-7 and 2-8). The availability provided by the One-Each Rule is considerably less than the 97 percent level achieved in the RIMSTOP mode.

TABLE 2-7. FIREFINDER AN/TPQ-36, RIMSTOP VS. ONE-EACH

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL + RIMSTOP	105	132	21	REF	REF	REF	$3,330,337	97
SIP MIN ERPSL + ONE-EACH	105	132	21	0	26	127	$2,200,474	<97

TABLE 2-8. FIREFINDER AN/TPQ-37, RIMSTOP VS. ONE-EACH

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL + RIMSTOP	26	147	17	REF	REF	REF	$2,966,171	97
SIP MIN ERPSL + ONE-EACH	26	146	17	0	50	138	$2,087,890	<97

Patriot Missile System

Separate initial provisioning analyses have been performed for the Patriot Fire Unit and the Patriot Command and Coordination Set (CCS). The A_s/cost curves for the Patriot Fire Unit (Figure 2-4) and the Command and Coordination Set (Figure 2-5) display the performances of the same four provisioning methods presented in the previous analyses. The cost curves reflect only the retail provisioning costs. The SIP determined wholesale provisioning and replenishment costs ($8,406,958 for the fire units and $779,941 for the CCS) need to be added to the retail costs to approximate the program's FY82 requirement.

The provisioning performances of the SIP and Zero Base ERPSL methods were examined at the SIP-determined retail budget level. The resulting ranges, depths, costs and supply availabilities are displayed in Tables 2-9 and 2-10.

The A_s/cost curve and the supporting analyses for the Patriot Fire Unit show an extremely low SIP stockage. This is attributable to the low density and high reliability of the Patriot. The availability resulting from the SIP stockage is so low that the system must have an ERPSL. When SIP stockage is as low as it is in the Patriot case, the SIP MIN ERPSL and the Zero Base ERPSL will display nearly identical performances, as they do in Tables 2-11 and 2-12.

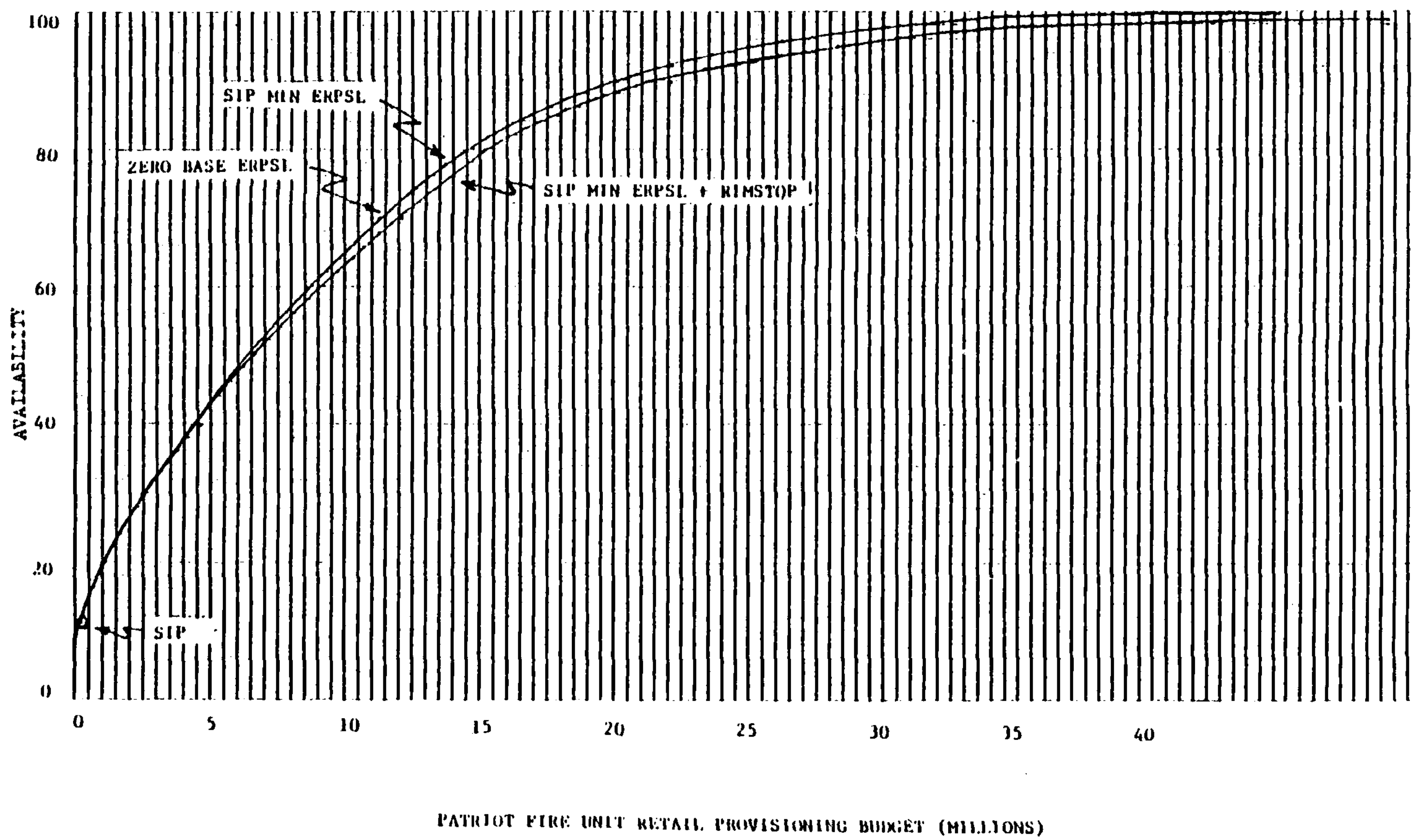


FIGURE 2-4. PATRIOT FIRE UNIT As/COST CURVES

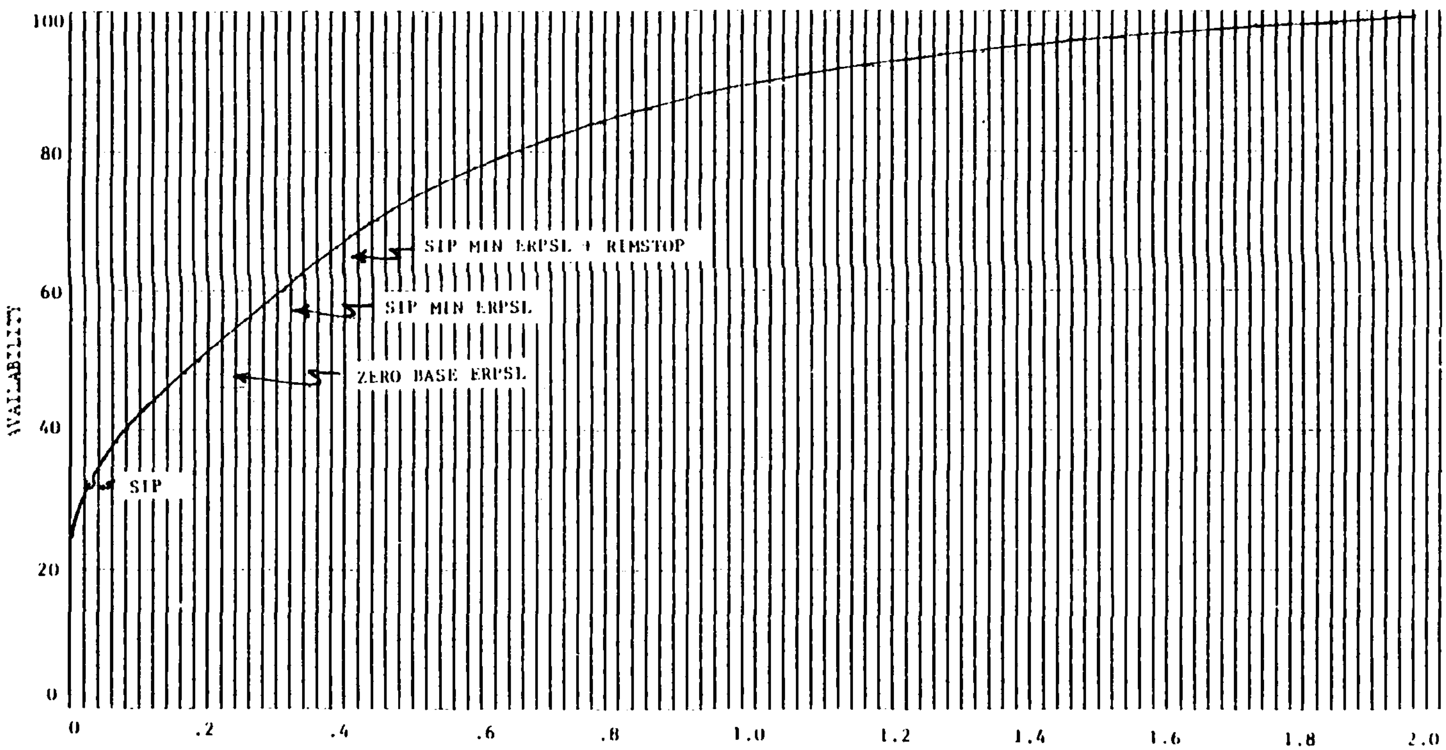


FIGURE 2-5. PATRIOT CCS As/COST CURVES

TABLE 2-9. SIP BUDGET LEVEL ANALYSIS, FIRE UNIT

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP	2	2	0	REF	REF	REF	$200,849	10.3
ZERO BASE ERPSL	2	41	0	40	662	1	$198,625	12.6

TABLE 2-10. SIP BUDGET LEVEL ANALYSIS, CCS

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP	1	1	0	REF	REF	REF	$18,872	30
ZERO BASE ERPSL	2	0	0	1	163	1	$18,737	30

TABLE 2-11. PATRIOT FIRE UNIT, 95 PERCENT AVAILABILITY LEVEL ANALYSIS

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL	645	373	0	REF	REF	REF	$25,402,819	95
SIP MIN ERPSL + RIMSTOP	559	203	0	145	487	71	$28,428,569	95
SIP MIN ERPSL + ONE-EACH	559	203	0	19	478	206	$22,563,133	<95
ZERO BASE ERPSL	645	373	0	1	702	0	$25,400,460	95

TABLE 2-12. PATRIOT CCS, 96 PERCENT AVAILABILITY LEVEL ANALYSIS

METHOD	RANGE			DEPTH			BUDGET	A_s(%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL	158	1	0	REF	REF	REF	$1,522,716	96
SIP MIN ERPSL + RIMSTOP	158	1	0	0	165	0	$1,522,716	96
SIP MIN ERPSL + ONE-EACH	158	1	0	0	149	16	$1,451,780	<96
ZERO BASE ERPSL	158	1	0	0	165	0	$1,522,716	96

RIMSTOP degrades the performance of either of the ERPSL methods when used for firing unit provisioning. However, the magnitude of the degradation in availability due to RIMSTOP is reasonably small. The small change in availability results from the fact that, even with an ERPSL, a large percentage of items are stocked at only one retail echelon and RIMSTOP will not affect those items. In no case was any item stocked at more than two retail echelons. For those items which were stocked at two echelons RIMSTOP forced the stockage into one echelon. When this occurred, the range of stockage decreased at each echelon and the depth of stockage was substantially increased in order to maintain the desired level of availability. The RIMSTOP-induced increase in retail depth cost an additional $3,025,750 with no improvement in availability.

The One-Each Rule degraded the firing unit availability by cutting almost $6 million from the SIP MIN ERPSL + RIMSTOP budget (Table 2-13). This was accomplished by reducing the depth of stockage on about 20 percent of the 703 APA secondary items. Since the SESAME model does not compute availability in the One-Each mode we have not determined the actual effect of One-Each on

firing unit availability. However, we believe the impact to be severe. The magnitude of the change may be approximated by the effects of RIMSTOP and the One-Each Rule on the Zero Base ERPSL provisioning of XM-1 discussed in Chapter 3 (see Figure 3-9).

TABLE 2-13. PATRIOT FIRE UNIT, RIMSTOP VS. ONE-EACH

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL + RIMSTOP	559	203	0	REF	REF	REF	$28,428,559	95
SIP MIN ERPSL + ONE-EACH	559	203	0	0	565	138	$22,563,133	<95

Finally, the effects of RIMSTOP and the One-Each Rule (Table 2-14) had little effect on CCS provisioning due to the almost total concentration of ERPSL stockage at one echelon (the organization level) and the fact that most items were already at One-Each quantities as a result of CCS low density and high reliability.

TABLE 2-14. PATRIOT CCS, RIMSTOP VS. ONE-EACH

METHOD	RANGE			DEPTH			BUDGET	A_s (%)
	ORG	DS	GS	HIGHER	SAME	LOWER		
SIP MIN ERPSL + RIMSTOP	158	1	0	REF	REF	REF	$1,522,716	96
SIP MIN ERPSL + ONE-EACH	158	1	0	0	149	16	$1,451,780	<96

Ground Laser Locator Designator (GLLD)

Because of its simplicity the GLLD provides an excellent example of the effects of SIP on availability and cost (Figure 2-6). For the period of study, FY 1982, 29 organizational units and nine DS units will be activated. All the provisioning methods analyzed concentrate the stockage at the DS units where corrective maintenance is performed. The SIP method provides an 82 percent availability for a cost of $10,193 (Table 2-15) while a Zero Base ERPSL method provides a 93 percent availability for only $6,983. The difference between these two approaches can be seen in the way they apportion the stock to each of the nine DS units (Table 2-16).

The Zero Base ERPSL stocked significantly higher quantities than SIP of all but one item. Both of these methods stocked nine of the ten APA secondary items. Adequate quantities of the two unstocked items, however, are available at the wholesale level. The SIP MIN ERPSL method, because it is saddled with the SIP-determined stockage, requires $12,303 to achieve the same 93 percent availability that the Zero Base ERPSL achieves for only $6,984.

Since the stock is concentrated at one echelon, the RIMSTOP has no effect on GLLD. The One-Each Rule only applies to items and echelons that do not qualify for SIP stockage. Therefore, the One-Each rule only affects one component for a total savings of $46.

An A_s/cost curve for the SIP plus ERPSL mode is shown on Figure 2-6 for GLLD. The limited excursion of the curve results from the nature of the SIP plus ERPSL method. Since, in this mode, the only items eligible for ERPSL stockage are those that do not qualify for any SIP stockage, the ERPSL can be applied to only one of the items. In the case of GLLD, the part not SIP-stocked is a low-failure item. This item could be ERPSL-stocked to great depth and still not have any appreciable effect on the overall availability of the system.

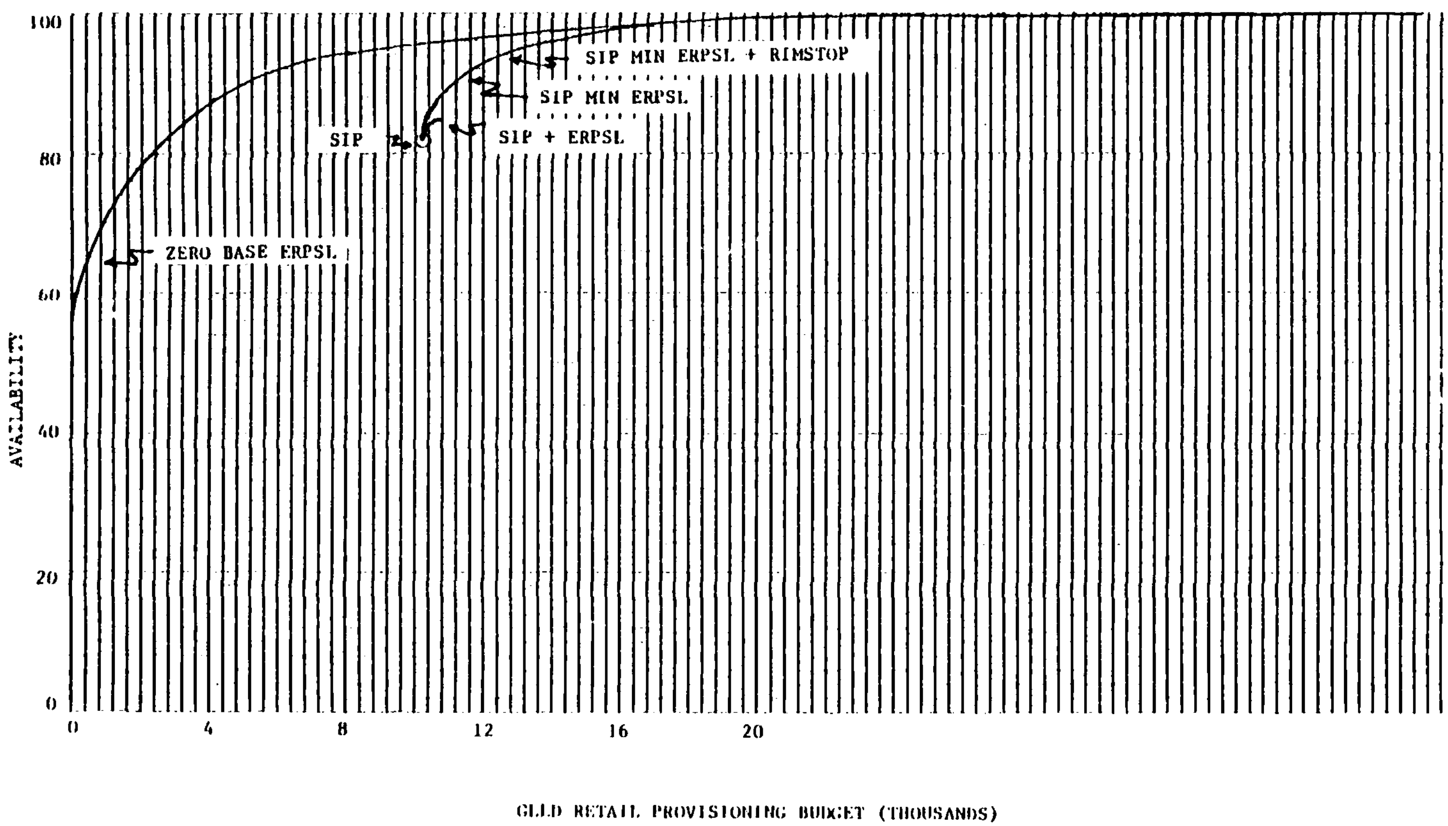


FIGURE 2-6. GLLD As/COST CURVES

TABLE 2-15. GLLD SHOPPING LIST

PART	PART COST	FAILURE FACTOR	SIP QUANTITY ORG	SIP QUANTITY DS	O BASE ERPSL QUANTITY ORG	O BASE ERPSL QUANTITY DS	SIP MIN ERPSL QUANTITY ORG	SIP MIN ERPSL QUANTITY DS	ERPSL RIMSTOP QUANTITY ORG	ERPSL RIMSTOP QUANTITY DS	ERPSL ONE-EACH QUANTITY ORG	ERPSL ONE-EACH QUANTITY DS	WHOLESALE ALL QUANTITY DEPOT
1	$831.81	27	0	9	0	0	0	9	0	9	0	9	29
2	31.50	26	0	9	0	27	0	18	0	18	0	18	31
3	27.70	54	0	18	0	45	0	36	0	36	0	36	64
4	27.95	44	0	18	0	36	0	27	0	27	0	27	52
5	5.09	11	0	0	0	27	0	18	0	18	0	9	13
6	13.77	20	0	9	0	27	0	18	0	18	0	18	24
7	13.36	36	0	9	0	36	0	27	0	27	0	27	43
8	38.81	35	0	9	0	27	0	18	0	18	0	18	41
9	36.62	40	0	18	0	36	0	18	0	18	0	18	47
10	9.36	50	0	18	29	27	29	18	29	18	29	18	63
TOTAL COST			$10192.59		$6983.73		$12303.00		$12303.00		$12257.19		$33198.35
AVAILABILITY			81.97		93.26		93.26		93.21		93.21		N/A

TABLE 2-16. GLLD DSU STOCKAGE DEPTH

DEPTH AT EACH DSU	
SIP	ZERO BASE ERPSL
0 ea of 1 Item	0 ea of 1 Item
1 ea of 5 Items	3 ea of 5 Items
2 ea of 4 Items	4 ea of 3 Items
	5 ea of 1 Item

CONCLUSIONS

In each of the four cases, the Zero Base ERPSL method is equal or superior to any other method. The SIP method provides far too little stockage when applied to low-density, high-reliability systems. The ineffectiveness of SIP in these cases makes the use of an optimization approach essential to achieve acceptable levels of availability.

Additionally, SIP was found to be clearly suboptimal when applied to the high-density XM-1 system.

The effectiveness of the SIP MIN ERPSL mode is dependent on the degree to which a weapon system qualifies for SIP stockage. For low-density, high-reliability systems that receive very little SIP stockage, the SIP MIN ERPSL performs as well as the Zero Base ERPSL. The cost-effectiveness of SIP MIN ERPSL decreases as the amount of SIP stockage increases.

The SIP plus ERPSL mode was found to be ineffective in substantially improving availability above the SIP-determined level.

The RIMSTOP, as implemented in the SESAME model, has no effect at best and substantially reduces provisioning cost-effectiveness at worst. Finally, the One-Each Rule can only compound the provisioning cost-effectiveness reduction induced by RIMSTOP.

3. SOME SENSITIVITY ANALYSES: OBSERVATIONS ON ROBUSTNESS

The initial provisioning environment is characterized by substantial uncertainty in the data used for provisioning computations. Therefore a fundamentally important issue with respect to the utility of any IP strategy is whether the stockage posture that the strategy produces is robust in the face of uncertainty, i.e., whether it performs well when a future eventuates that is different than it was expected to be when the stockage posture was determined. By performing well we mean, as always, that the policy is cost-effective with respect to availability and total cost. This Chapter discusses the relative vulnerability of alternative methods to uncertainty.

UNIT PRICE SENSITIVITY

Unit prices appear to be subject to a high degree of uncertainty in the early period of weapon system development. Actual price changes for 59 APA secondary items on the XM-1 tank over approximately a one-year period were collected and analysed. The results showed that early price estimates were generally significantly lower than later prices. The tendency of unit price estimates to increase over time was confirmed by both the commodity commands and program management personnel.

It is important to note that the concern about data uncertainty is frequently stated as a fear that the uncertainty will result in overprovisioning; therefore, IP policy has been designed to produce conservative initial spares investment behavior. However, the early uncertainty in unit price estimates will result in budgets that are already conservative. By conservative we mean a risk preference for buying too few spares rather than too many.

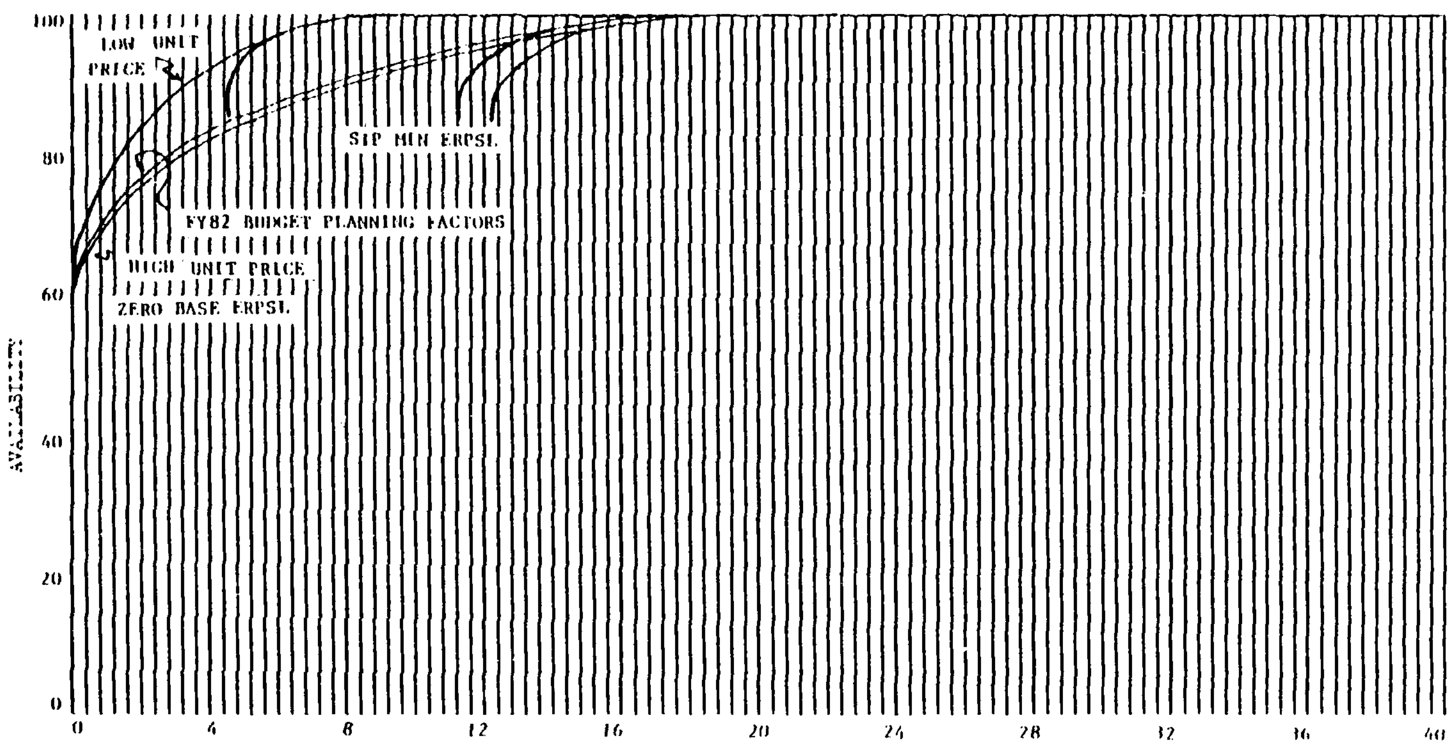
Two sets of A_s/cost curves for Europe, for the 59 XM-1 APA secondary items, one for retail only and the other for retail and wholesale, are shown in Figures 3-1 and 3-2. The low cost estimates for the items form one curve and the high cost estimates form a second curve. The A_s/cost curve that actually reflects the current planning prices is also plotted. These curves were plotted for both the *SIP MIN ERPSL and Zero Base ERPSL methods*. The budget excursion between the low price case and the high price case is a measure of the sensitivity of each method to that range of price uncertainty. Clearly, the Zero Base ERPSL method is more robust than the SIP MIN ERPSL method. At 85 percent availability, the retail budget excursion for Zero Base ERPSL was about $3 million while the SIP MIN ERPSL excursion was about $7.5 million, a rather dramatic difference.

FAILURE FACTOR SENSITIVITY

Changes in failure factors for the same time period and for the same 59 XM-1 APA secondary items underlie the A_s/cost curves in Figures 3-3 and 3-4. Again, the Zero Base ERPSL method was found to be less sensitive to uncertainty than the SIP MIN ERPSL. At 88 percent availability, the retail budget excursion for the Zero Base ERPSL was $5.2 million while the SIP MIN ERPSL excursion was $7.2 million.

As was the case with price changes, early failure rate estimates were generally lower than later estimates. Thus, the effect of early failure factor uncertainty is to produce conservatism in early budget estimates.

Finally, price and failure factor data have been combined and the resultant A_s/cost sensitivity curves for retail and retail plus wholesale stockage are shown in Figures 3-5 and 3-6.

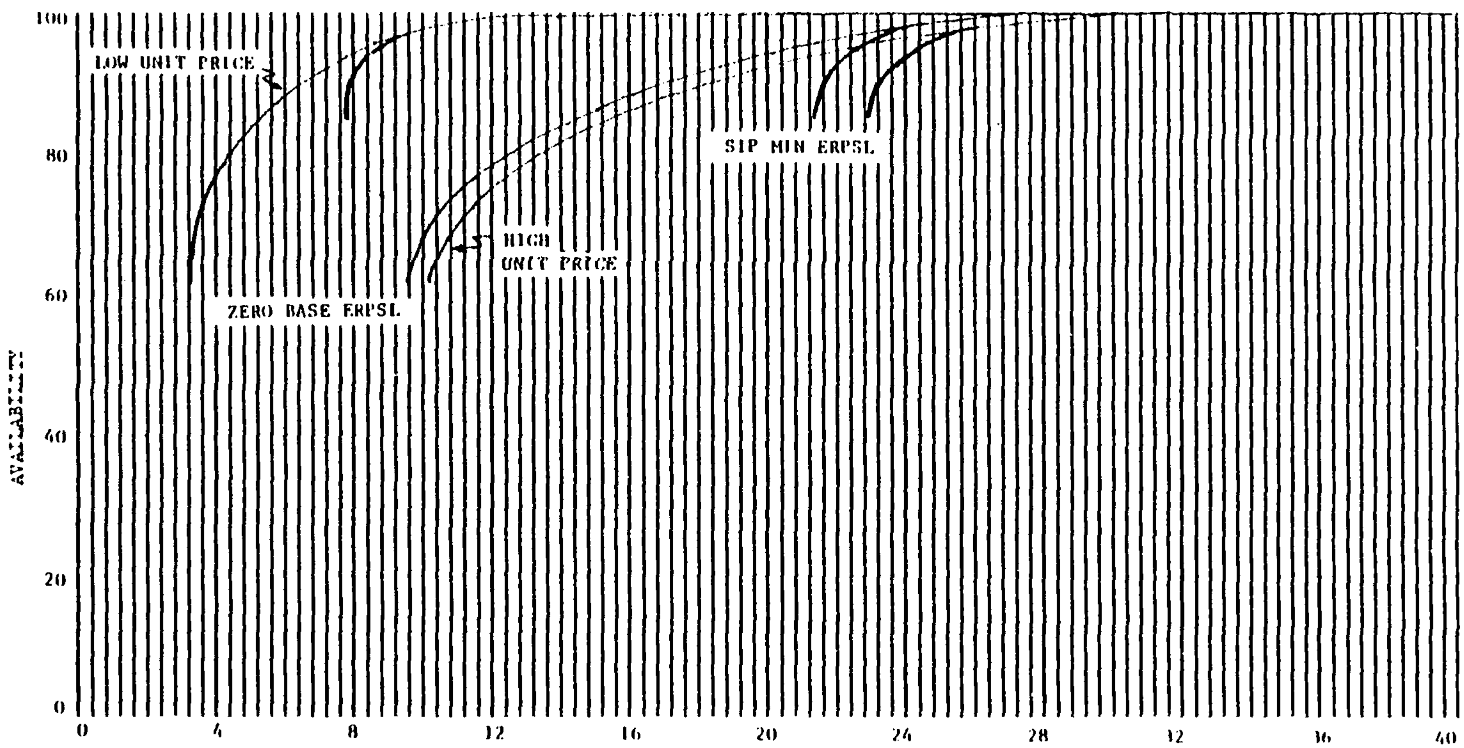


XM-1 RETAIL PROVISIONING BUDGET (MILLIONS)

UNIT PRICE SENSITIVITY (59 ITEM SAMPLE)

(FY82, EUROPE, RETAIL ONLY)

FIGURE 3-1. XM-1 UNIT PRICE SENSITIVITY (RETAIL)

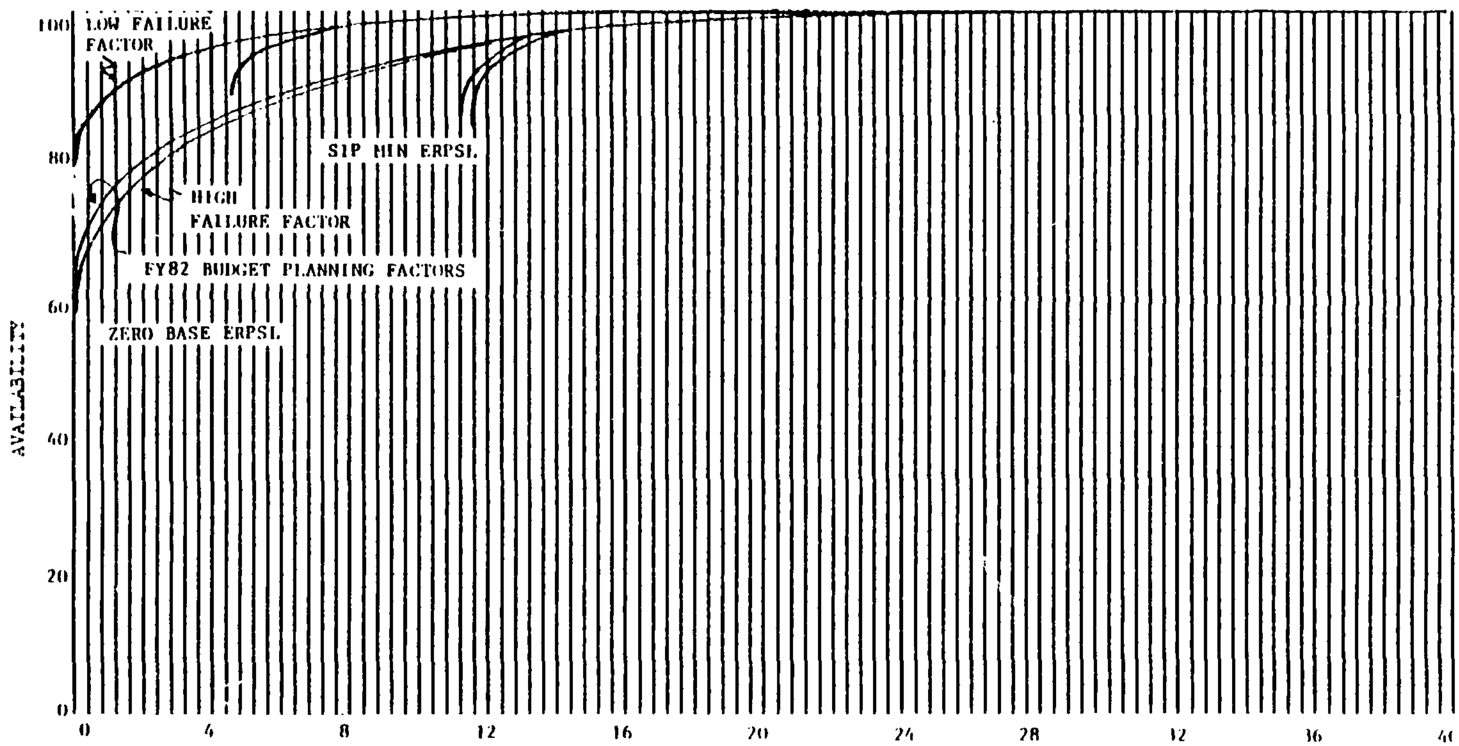


PROVISIONING BUDGET (MILLIONS)

XM-1 UNIT PRICE SENSITIVITY (59 ITEM SAMPLE)

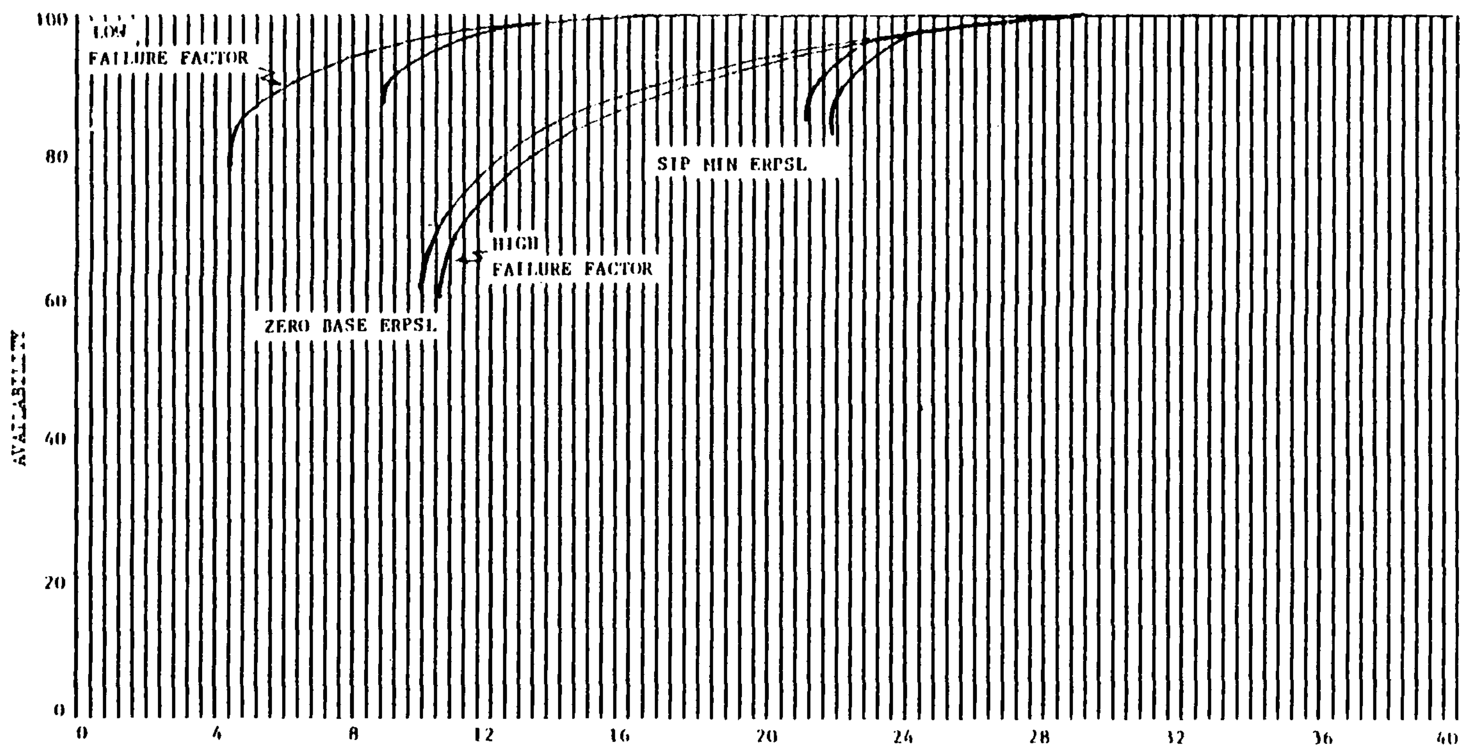
(FY82, EUROPE, WHOLESALE + RETAIL)

FIGURE 3-2. XM-1 UNIT PRICE SENSITIVITY (RETAIL AND WHOLESALE)



XM 1 RETAIL PROVISIONING BUDGET (MILLIONS)
FAILURE FACTOR SENSITIVITY (59 ITEM SAMPLE)
(FY 82, EUROPE, RETAIL ONLY)

FIGURE 3-3. XM 1 FAILURE FACTOR SENSITIVITY (RETAIL)

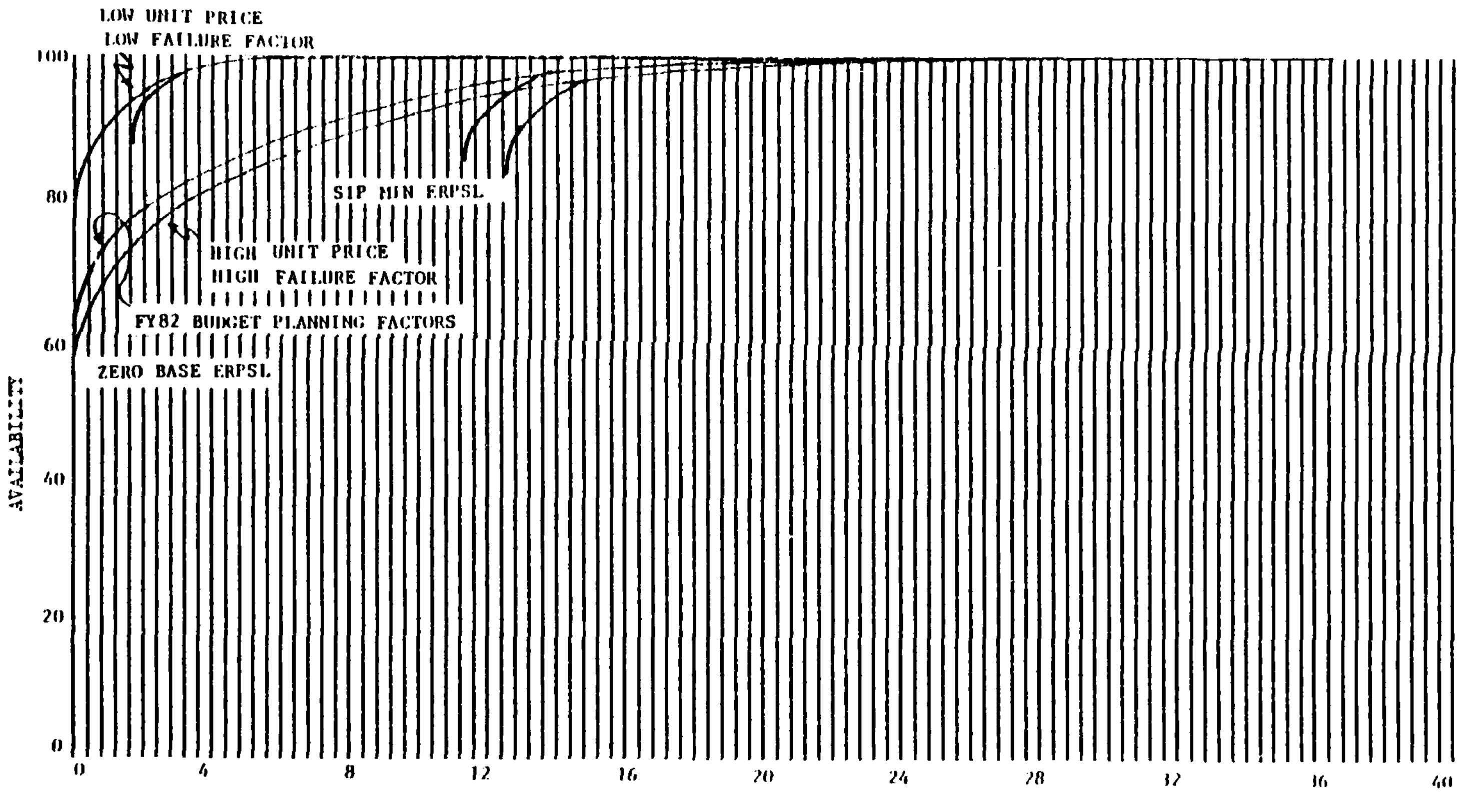


XM 1 PROVISIONING BUDGET (MILLIONS)

FAILURE FACTOR SENSITIVITY (59 ITEM SAMPLE)

(FY82, EUROPE, WHOLESALE + RETAIL, WITHOUT REPLENISHMENT)

FIGURE 3-4. XM 1 FAILURE FACTOR SENSITIVITY (RETAIL AND WHOLESALE)

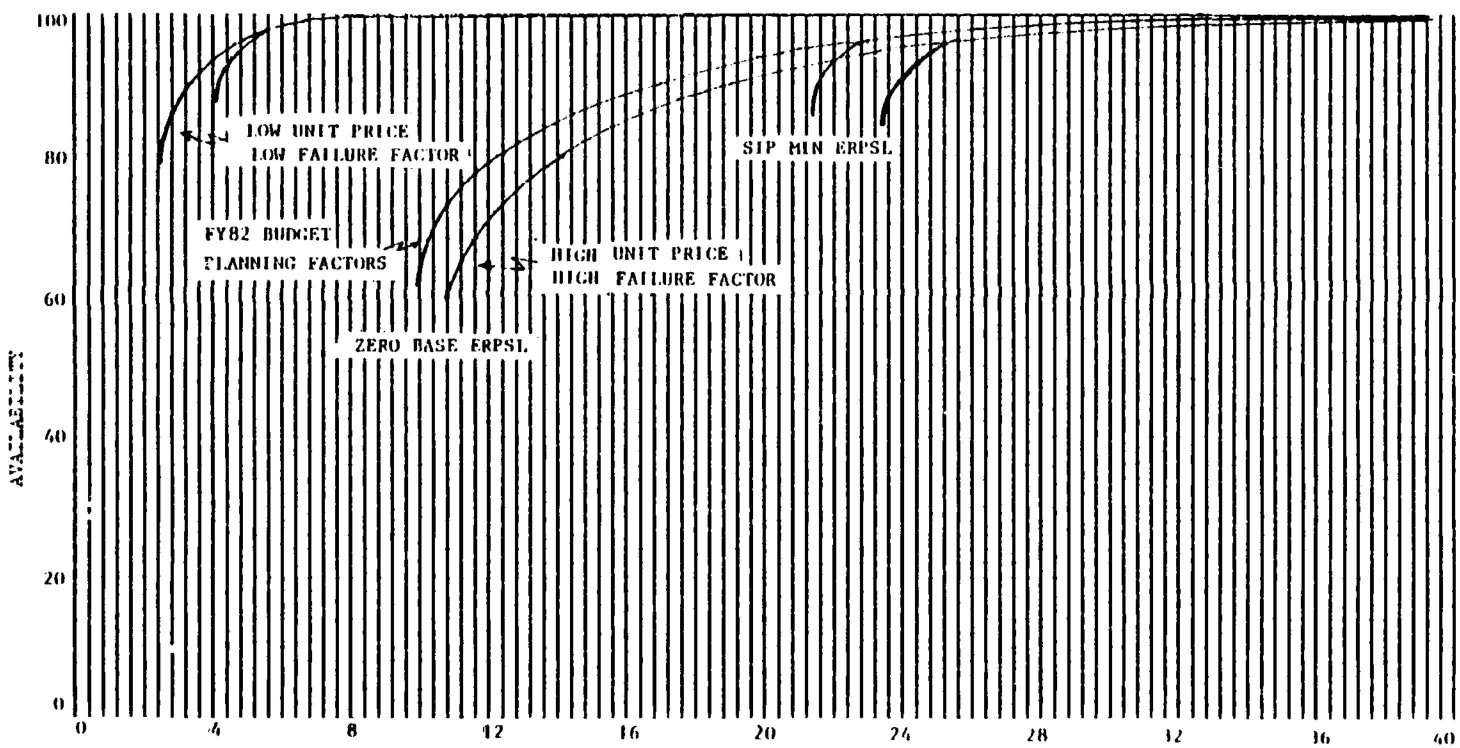


XM 1 RETAIL PROVISIONING BUDGET (MILLIONS)

UNIT PRICE + FAILURE FACTOR SENSITIVITY (59 ITEM SAMPLE)

(FY82, EUROPE, RETAIL ONLY)

FIGURE 3-5. XM 1 COMBINED SENSITIVITY (RETAIL)



PROVISIONING BUDGET (MILLIONS)

XM 1 UNIT PRICE + FAILURE FACTOR SENSITIVITY (59 ITEM SAMPLE)

(FY82, EUROPE, WHOLESALE + RETAIL)

FIGURE 3-6. XM 1 COMBINED SENSITIVITY (RETAIL AND WHOLESALE)

ORDER-AND-SHIP TIME SENSITIVITY

A sensitivity analysis to assess the robustness of the SIP MIN ERPSL and Zero Base ERPSL to uncertainty in order-and-ship time (OST), based on the same 59 XM-1 APA secondary items as before, is shown in Figure 3-7. At 88 percent availability, the retail budget excursion for the Zero Base ERPSL method was approximately the same as for the SIP MIN ERPSL for the same $\pm$ 28.5 percent change in OST.

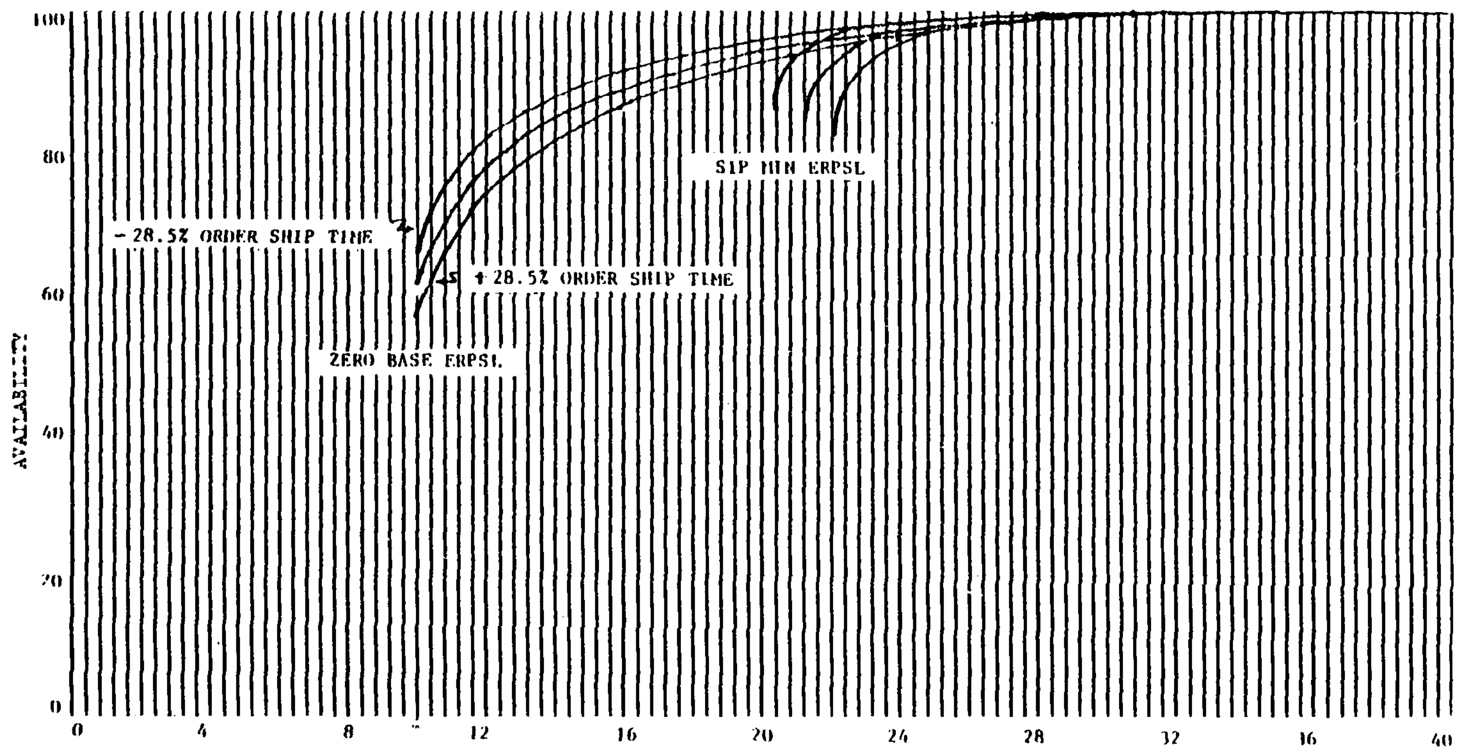
OPERATING UNITS OF PROGRAM

The Operating Units of Program (OUP) factor represents the number of end items supported by each organization or claimant. The SESAME model does not accommodate more than one OUP configuration per echelon, nor does it accommodate deployment strategies that change OUP levels over the system deployment period, e.g., activating early claimants with less than a full complement of weapon systems.

The sensitivity analysis for the OUP parameter used the same 59 items as before. At 86 percent availability the retail budget excursion for the Zero Base ERPSL was \$5.6 million while it was \$7.2 million for the SIP MIN ERPSL. (See Figure 3-8.)

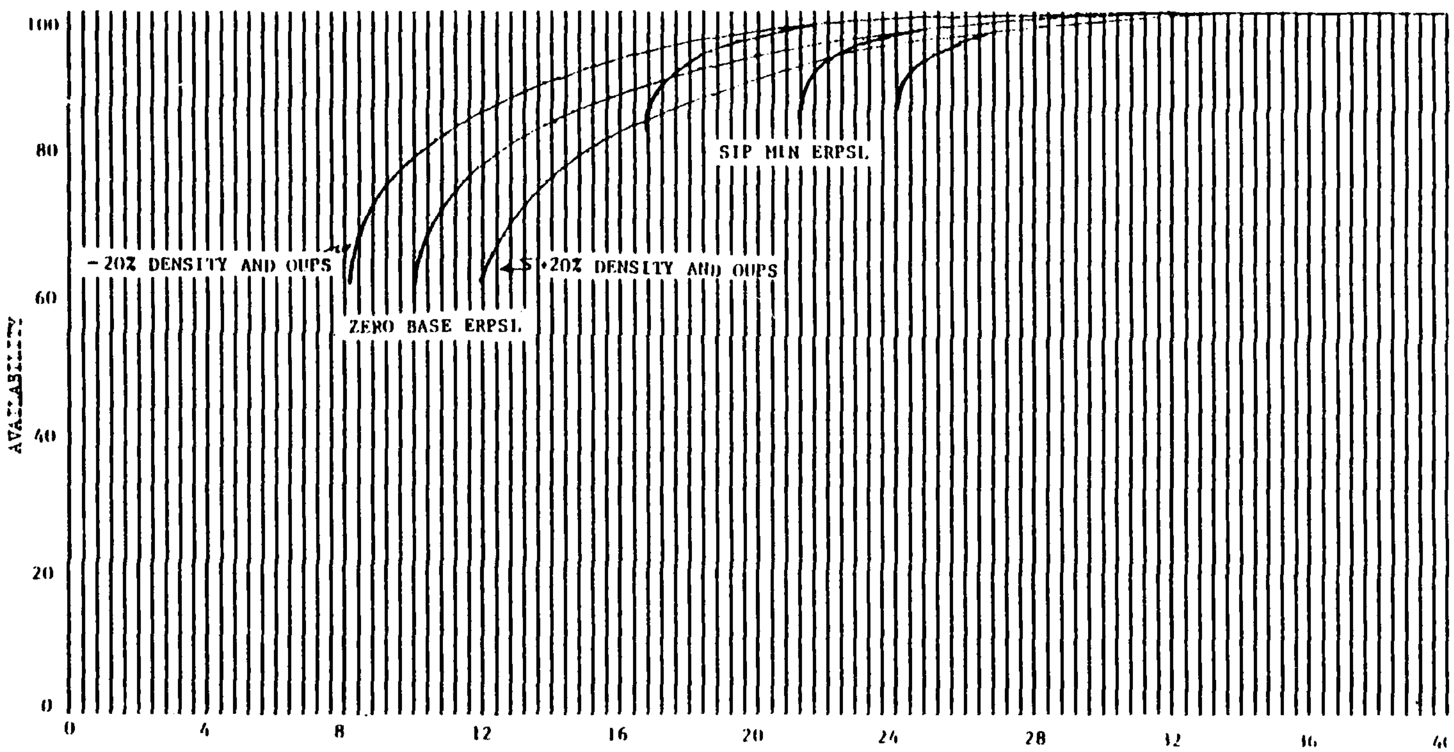
PROVISIONING MODELS AND METHODS

Significant strides have been made in recent years to advance the state of the art of inventory theory and provisioning model technology. There is, however, legitimate concern within DoD and in the logistics community that the quality of the program planning data essential to use these new models has not kept pace with model development. This concern has led some to suggest that time spent in making further improvements in provisioning model technology is unproductive so long as significant uncertainty exists in the data. Unquestionably, efforts should be made to improve the quality of the program



XM-1 PROVISIONING BUDGET (MILLIONS)
ORDER SHIP TIME SENSITIVITY (59 ITEM SAMPLE)
(FY82, EUROPE, RETAIL + WHOLESALE)

FIGURE 3-7. XM-1 OST SENSITIVITY



XM-1 PROVISIONING BUDGET (MILLIONS)
DENSITY & OUPS SENSITIVITY (59 ITEM SAMPLE)
(FY82, EUROPE, RETAIL + WHOLESALE)

FIGURE 3-8. XM-1 DENSITY AND OUP SENSITIVITY

data. These efforts, however, should be in parallel with continuing improvements in model capability. Clearly, optimization models produce stockage postures that perform better in the face of uncertainty than item-oriented methods do.

Improved Model Logic and Assumptions

Much of the uncertainty associated with existing provisioning models emanates from the techniques, assumptions, and logic embodied in the models. If these are not sound, then it is unlikely that the most cost-effective provisioning will result from their use.

We have examined some of the current Army-approved provisioning methods and find several areas where assumptions or logic could be substantially improved. This statement should not be taken to mean that the current models should not be used for budget estimating and initial provisioning; on the contrary, the existing models appear to be greatly superior to the alternative techniques currently available to the Army's logistics planners. It does mean, however, that much work remains to be done which could substantially advance the state of the art of provisioning models.

PROVISIONING POLICY AND MANAGEMENT

A number of policy, organizational and management factors also impact the accuracy of provisioning requirements computations. The initial spares requirements computed for each claimant may be quite different than the spares actually ordered by the unit. The division of provisioning responsibilities among various commodity commands tends to obscure the system's provisioning optimization objective. In general, constraints (such as RIMSTOP) placed on the process reduce its cost-effectiveness. These and other problems are examined in this section.

Constraints

Constraints placed on the forecasting process may increase rather than decrease the error between forecast and actual requirements. Two constraints, RIMSTOP and the One-Each Rule, actually result in lowered provisioning cost-effectiveness. The effects of these two constraints on provisioning optimization are significant when used with the Zero Base ERPSL method. Figure 3-9 illustrates the effect on availability and budget when these constraints are applied to the full 162 XM-1 APA secondary items for the European theater. For a budget expenditure of $7 million the unconstrained Zero Base ERPSL will provide a 91 percent availability while the RIMSTOP constraint will provide only 73 percent availability. The One-Each Rule has not yielded more than 49 percent availability. Clearly, the RIMSTOP and the One-Each Rule should never be applied to any method which attempts to optimize the initial provisioning stockage.

Organization of Provisioners

A potential problem in initial provisioning lies in the division of provisioning responsibilities among the various commodity commands. Lack of coordination among various commodity commands assigned responsibility for portions of a weapon system can be a problem. Each individual command is concerned with provisioning its own items and does so using its own selected provisioning methodology. A weapon system is unlikely to be provisioned optimally without system level integration and coordination among the commands involved in the provisioning process.

Initial Provisioning Policy

There is concern and doubt, in some quarters, as to whether optimization models really offer any advantage over an item-oriented approach when there is significant uncertainty in the input data. To answer these concerns

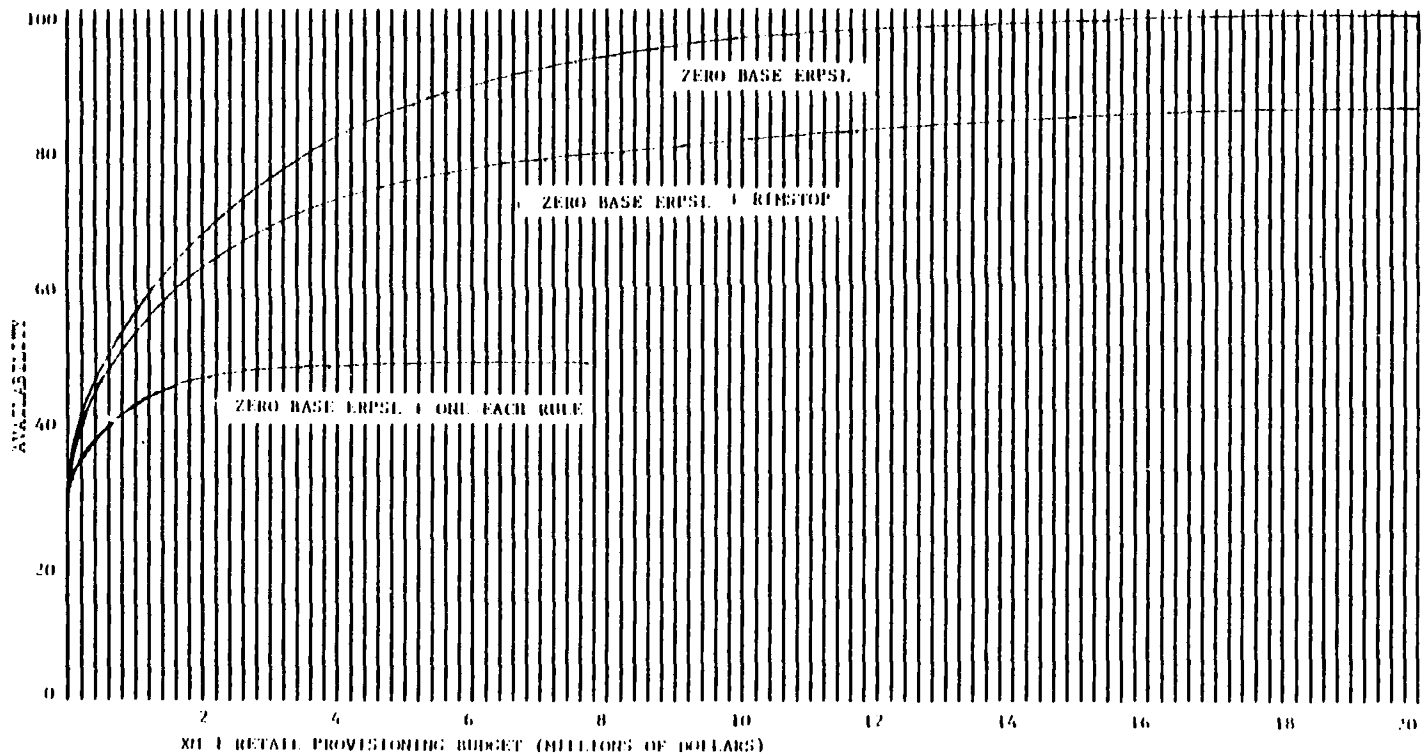


FIGURE 3-9. XM-1 RIMSTOP AND ONE-EACH RULE EFFECTS (162 ITEMS)

and better understand the dynamics of initial provisioning methods under uncertainty we partitioned the 162 XM-1 APA secondary items into three categories. Category one consisted of the items stocked in greater quantities by Zero Base ERPSL than by SIP MIN ERPSL at the SIP-determined budget level; category two contained the items stocked in the same quantities by the two methods; category three items were stocked in greater quantities by SIP than by Zero Base ERPSL. There were 108 items in the first category, 50 in the second, and four items in the third (see Table 2-1).

Our sensitivity analyses for these categories consisted of changing the unit price and failure factors for items in each category by ± 20 percent. Our choice of 20 percent was arbitrary; it is great enough to show the character of the change. We then computed the implied budget excursion for an 80 percent availability from the A_s/cost curves which appear in Figures 3-10 through 3-13. Table 3-1 shows the approximate retail budget excursion for both Zero Base ERPSL and SIP MIN ERPSL.

TABLE 3-1. XM-1 PROVISIONING METHOD SENSITIVITY

SENSITIVITY FACTOR	EXCURSION IN RETAIL BUDGET	
	ZERO BASE ERPSL	SIP MIN ERPSL
± 20% CHANGE IN UNIT PRICE FOR ALL 108 CATEGORY ONE ITEMS (FIGURE 4-10)	$ 1.2 MILLION	$ .95 MILLION
± 20% CHANGE IN FAILURE FACTOR FOR ALL 108 CATEGORY ONE ITEMS (FIGURE 4-12)	$ 1.1 MILLION	$ 1.0 MILLION
± 20% CHANGE IN UNIT PRICE FOR ALL FOUR CATEGORY THREE ITEMS (FIGURE 4-11)	$ .4 MILLION	$1.75 MILLION
± 20% CHANGE IN FAILURE FACTOR FOR ALL FOUR CATEGORY THREE ITEMS (FIGURE 4-13)	$ .8 MILLION	$ 2.1 MILLION

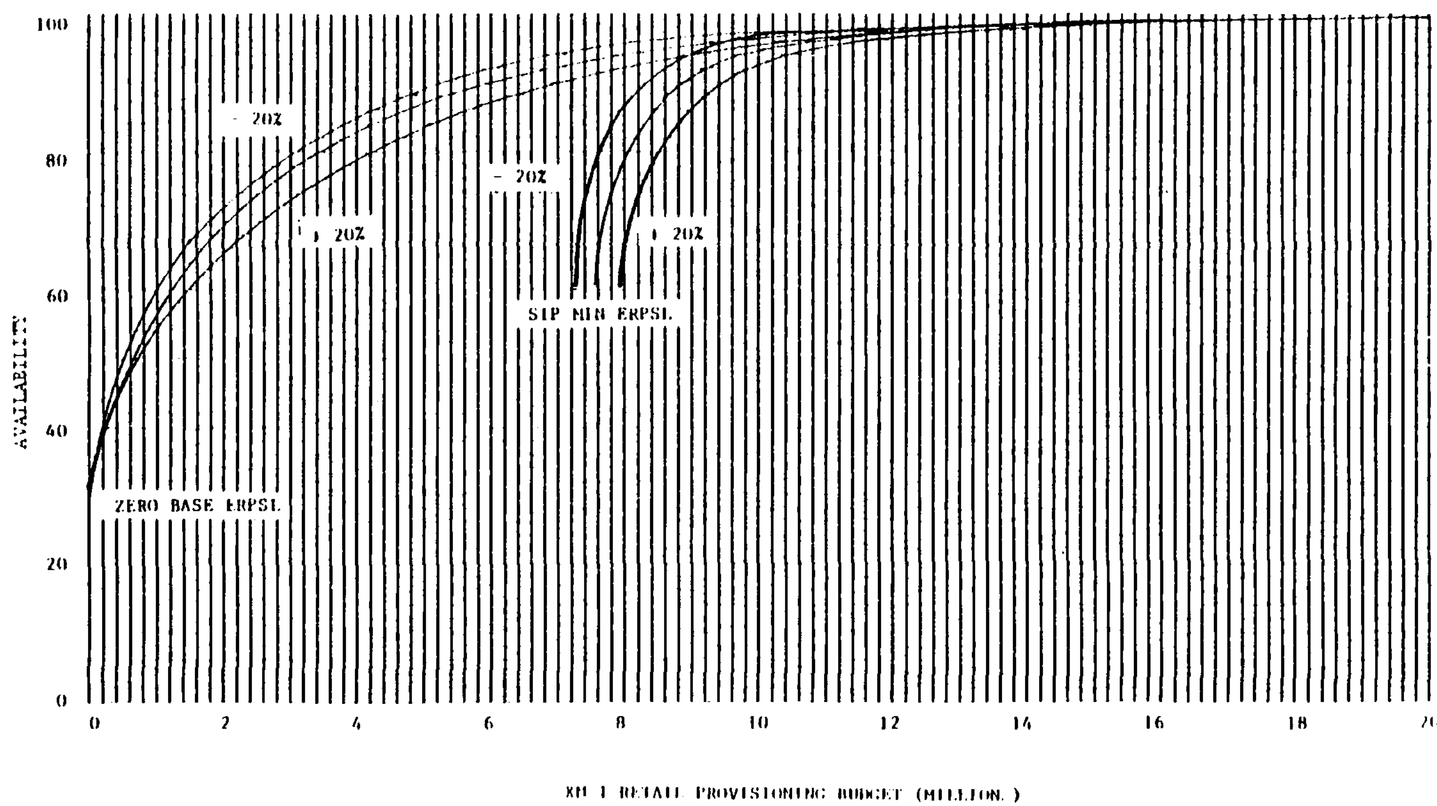


FIGURE 3-10. ± 20% UNIT PRICE CHANGE (CATEGORY ONE ITEMS)

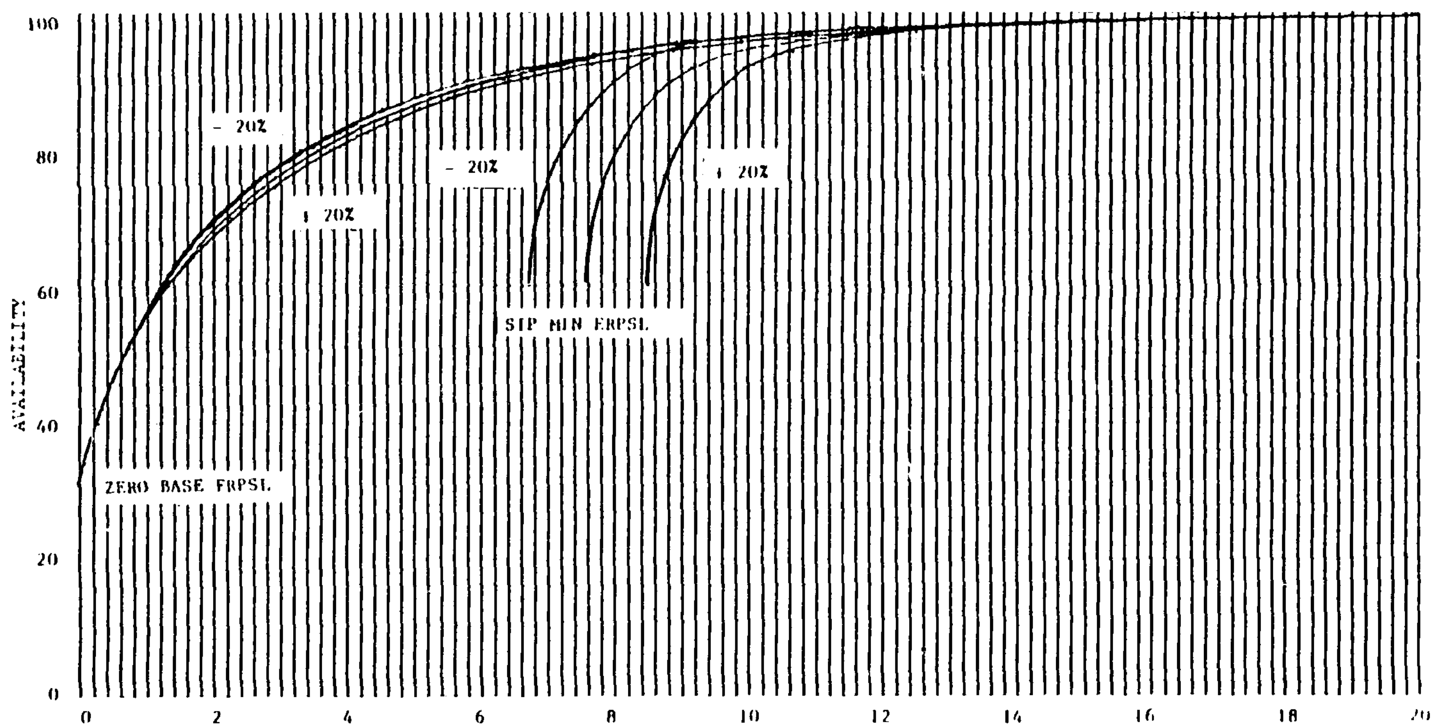


FIGURE 3-11. ± 20% UNIT PRICE CHANGE, CATEGORY TWO ITEMS

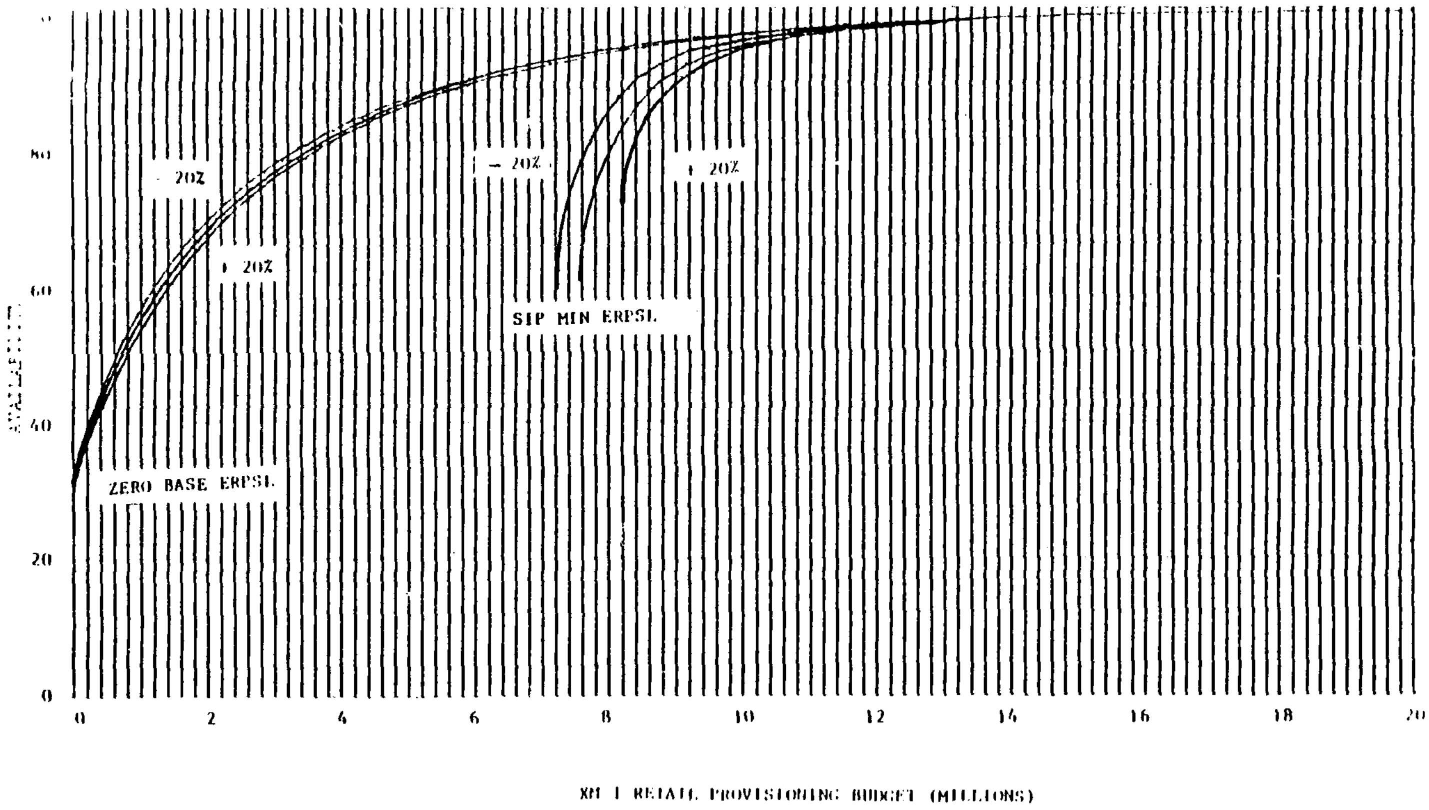


FIGURE 3-12. ± 20% FAILURE FACTOR CHANGE, CATEGORY ONE ITEMS

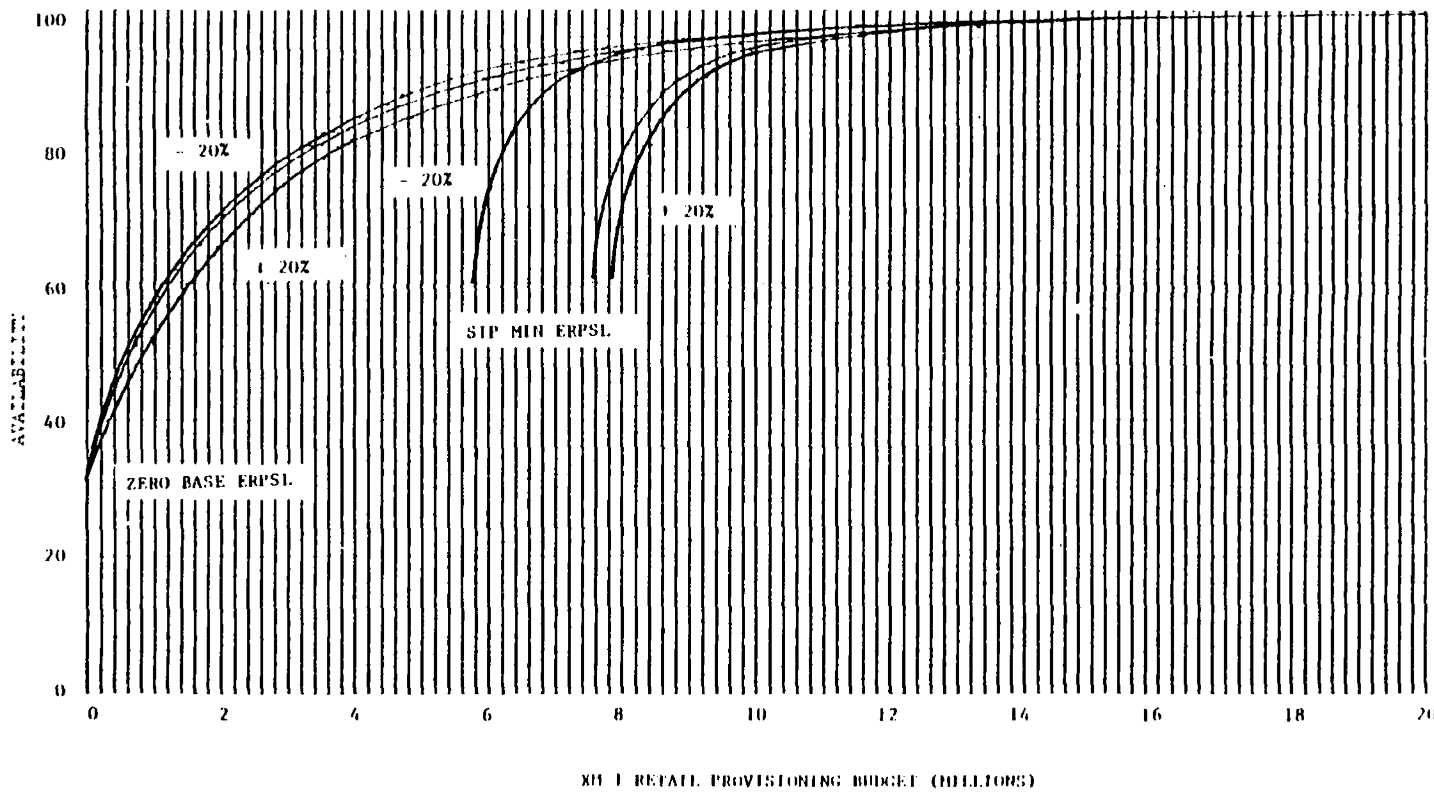


FIGURE 5-11. ± 20% FAILURE FACTOR CHANGE, CATEGORY TWO ITEMS

The analyses suggest that the Zero Base ERPSL sensitivity is slightly higher than that of SIP MIN ERPSL for category one items. The reason for this is straightforward. The Zero Base ERPSL method stocks significantly higher quantities of low cost items (the majority of which are the items in category one) and is therefore more sensitive to changes in those items than is SIP MIN ERPSL. However, it is important to note that although the factors for all 108 low cost items were changed by $\pm$ 20 percent, the difference in budget excursions between the two methods is relatively small.

The analyses also suggest that Zero Base ERPSL is significantly less sensitive than SIP MIN ERPSL for category three items--the high cost items. In fact, when the factors for only four high cost items were changed by $\pm$ 20 percent, the difference in budget excursions for the two methods was substantially greater, as is shown in Table 3-1. Clearly, the greater overall budget risk is presented by the use of the SIP methodology.

Sensitivity Analyses of Critical Items

Spares provisioning budgets are determined well in advance (approximately two years) of the actual procurement of the spares. This poses a significant problem in that there is generally much uncertainty surrounding early item-specific estimates of unit prices and failure rates. In the years between determining the spares budget and provisioning for the spares, the uncertainty surrounding these factors diminishes as more knowledge about the items is obtained. New spares requirements computations based on this improved data may present the provisioner with potentially large differences between the previously determined budget and newly computed spares requirements. Therefore, there is considerable advantage to employing a budgeting-procurement methodology which will not only provide the most cost-effective mix of spares, but which will also provide the least difference between the initial budget submission and the subsequent funds required for spares procurement.

The following analyses examine the sensitivities of budget levels and availabilities under the ZERO BASE and SIP MIN methodologies to changes in prices and failure factors for specified critical item subsets of APA secondary item spares. We have defined as critical subsets those items that have (1) high unit prices, (2) high failure factors, (3) high failure-costs (the product of the item's failure factor and unit price), and (4) high engineering change proposal (ECP) probabilities. The selection criteria for each subset is given in Table 3-2. A fifth subset, long-lead-time items, was determined to be essentially the same as the high unit price subset.

TABLE 3-2. SELECTION CRITERIA

SUBSET	QUANTITY	CRITERIA
SUBSET 1	9 ITEMS	UNIT PRICE > $25,000
SUBSET 2	9 ITEMS	FAILURE FACTOR > 15
SUBSET 3	9 ITEMS	UNIT PRICE X FAILURE FACTOR > $325,000
SUBSET 4	9 ITEMS	HIGH PROBABILITY OF ECP ACTION*

* Based on the judgment of XM-1 logistics planners.

The nine items in each subset represent between five and six percent of the total number of provisioned APA secondary items. For each subset, the retail stockage quantity was determined at a 70 percent availability. The sensitivity analyses were performed for ± 20 percent changes in failure factors and unit prices. Tables 3-3 through 3-6 show the price, failure, and ECP data for each item as well as the quantity of spares of an item under each provisioning method. Quantities are indicated for the baseline and plus and minus 20 percent variations of the variable under analysis.

TABLE 3-3. HIGH UNIT PRICE SUBSET

SET # 1						ZERO BASE ±20% FF RETAIL QUANT			SIP MIN ±20% FF RETAIL QUANT			ZERO BASE ±20% UP RETAIL QUANT			SIP MIN ±20% UP RETAIL QUANT		
ITEM	UNIT PRICE	FAILURE FACTOR	UNIT PRICE X FAILURE FACTOR	HIGH ECP	COMMON SETS	-	B	+	-	B	+	-	B	+	-	B	+
155	417,505	6	2,505,030		3	0	0	0	1	2	2	0	0	0	2	2	2
157	206,965	8	1,655,720		3	0	1	1	2	3	4	1	1	0	3	3	3
156	187,000	12	2,240,000		3	1	2	2	4	10	11	2	2	1	10	10	10
160	174,135	4	696,540		3	0	0	0	1	2	2	0	0	0	2	2	2
21	93,201	23	2,143,623	X	2,3,4	1	2	2	13	14	15	2	2	1	14	14	14
158	40,716	4	162,864			0	1	1	1	2	2	1	1	0	2	2	2
35	36,809	15	552,135		3	0	0	1	6	11	12	0	0	0	11	11	11
43	37,012	10	370,120	X	3,4	0	1	1	2	2	2	1	1	0	2	2	2
27	28,324	10	283,240	X	4	1	2	3	3	4	4	3	2	2	4	4	4
BASELINE RETAIL BUDGET (162 ITEMS)						$2.85M			$7.87M			$2.85M			$7.87M		
BASELINE AVAILABILITY (A_S)						70%			70%			70%			70%		

TABLE 3-4. HIGH FAILURE FACTOR SUBSET

SET # 2

ITEM	UNIT PRICE	FAILURE FACTOR	UNIT PRICE X FAILURE FACTOR	HIGH ECP	COMMON SETS	ZERO BASE ±20% FF RETAIL QUANT − B +	SIP MIN ±20% FF RETAIL QUANT − B +	ZERO BASE ±20% UP RETAIL QUANT − B +	SIP MIN ±20% UP RETAIL QUANT − B +
84	2,200	90	198,000			9 9 9	9 9 9	9 9 9	9 9 9
4	3,295	36	118,620			21 26 29	21 24 27	27 26 25	24 24 24
150	777	30	23,310			21 25 30	17 21 24	26 25 24	22 21 20
3	3,375	25	84,375			13 15 17	12 14 16	15 15 14	14 14 14
46	1,607	25	40,175	X	4	8 8 9	7 8 8	9 8 8	8 8 8
21	93,201	23	2,143,623	X	1,3,4	1 2 2	13 14 15	2 2 2	14 14 14
19	18,983	20	379,660	X	3,4	2 6 7	13 14 14	7 6 6	14 14 14
136	6,545	20	130,900			8 9 10	8 9 10	9 9 9	9 9 9
151	350	20	7,000			13 16 19	12 14 17	17 16 16	15 14 14
BASELINE RETAIL BUDGET (162 ITEMS)						$2.85M	$7.87M	$2.85M	$7.87M
BASELINE AVAILABILITY (A_S)						70%	70%	70%	70%

TABLE 3-5. HIGH FAILURE COST SUBSET

SET # 3						ZERO BASE ±20% FF RETAIL QUANT			STP MIN ±20% FF RETAIL QUANT			ZERO BASE ±20% UP RETAIL QUANT			STP MIN ±20% UP RETAIL QUANT		
ITEM	UNIT PRICE	FAILURE FACTOR	UNIT PRICE X FAILURE FACTOR	HIGH ECP	COMMON SETS	-	B	+	-	B	+	-	B	+	-	B	+
155	417,505	6	2,505,030		1	0	0	0	1	2	2	0	0	0	2	2	2
156	187,000	12	2,240,000		1	1	2	2	4	10	11	2	2	1	10	10	10
21	93,201	23	2,143,623	X	1,2,4	1	2	2	13	14	15	2	2	1	14	14	14
157	206,965	8	1,655,720		1	0	1	1	2	3	4	1	1	0	3	3	3
160	174,135	4	696,540		1	0	0	0	1	2	2	0	0	0	2	2	2
35	36,809	15	552,135		1	0	0	1	6	11	12	0	0	0	11	11	11
19	18,983	20	379,660	X	2,4	2	6	7	13	14	14	7	6	2	14	14	14
43	37,012	10	370,120	X	1,4	1	1	1	2	2	2	1	1	0	2	2	2
18	21,786	15	326,790	X	4	0	1	1	6	11	12	1	1	0	11	11	11
BASELINE RETAIL BUDGET (162 ITEMS)						$2.85M			$7.87M			$2.85M			$7.87M		
BASELINE AVAILABILITY (A_s)						70%			70%			70%			70%		

TABLE 3-6. HIGH ECP PROBABILITY SUBSET

SET # 4						ZERO BASE +20% FF			SIP MIN +20% FF			ZERO BASE +20% UP			SIP MIN +20% UP		
						RETAIL QUANT			RETAIL QUANT			RETAIL QUANT			RETAIL QUANT		
ITEM	UNIT PRICE	FAILURE FACTOR	UNIT PRICE X FAILURE FACTOR	HIGH ECP	COMMON SETS	-	B	+	-	B	+	-	B	+		B	+
46	1,607	25	40,175	X	2	3	8	9	7	8	8	9	8	3	8	8	7
21	93,201	23	2,143,623	X	1,2,3	1	2	2	13	14	15	2	2	1	14	14	14
19	18,983	20	379,660	X	2,3	2	6	7	13	14	14	7	6	2	14	14	14
20	23,480	11	258,280	X		0	1	1	2	7	7	1	1	1	7	7	7
43	37,012	10	370,120	X	1,3	0	1	1	2	2	2	1	1	0	2	2	2
27	28,324	10	283,240	X	1	1	2	3	3	4	4	3	2	2	4	4	4
44	12,502	10	125,020	X		2	4	4	3	4	5	4	4	3	4	4	4
37	3,586	7	25,102	X		2	7	7	2	3	3	7	7	2	3	3	2
26	14,185	5	70,925	X		0	0	0	0	0	0	0	0	0	0	0	0
BASELINE RETAIL BUDGET (162 ITEMS)						$2.85M			$7.87M			$2.85M			$7.87M		
BASELINE AVAILABILITY (A_S)						70%			70%			70%			70%		

Two sets of A_s/cost curves were generated for each critical subset. The first of these depicts the availability/cost relationship for a $\pm$ 20 percent change in unit price and are given in Figures 3-14 through 3-17. The second set of curves depicts the availability/cost relationship for a $\pm$ 20 percent change in failure factor and are given in Figures 3-18 through 3-21. Each curve set represents the availability/cost relationship for all 162 XM-1 APA secondary items with only the factors for the nine critical items being varied.

Budget Sensitivity. The analyses show the ZERO BASE determined budget to be less sensitive than the SIP MIN determined budget to changes in unit price for all four of the critical item subsets. This is because the ZERO BASE methodology considers unit price to be a major factor in the determination of the most cost-effective spares mix. As price increases the ZERO BASE method will buy less of the item and as price decreases it will buy more. This works to maintain a reasonably constant budget level in the face of changes in unit price. The SIP MIN methodology, on the other hand, does not take unit price into consideration when determining the SIP baseline quantity of initial spares. Therefore, the entire cost differential which results from a unit cost change will be reflected in the baseline provisioning budget requirement.

The analyses also show the ZERO BASE determined budget to be less sensitive than the SIP MIN budget to failure factor changes when those changes occur primarily in the high unit price (long-lead-time) items. (See Figures 3-18 and 3-20.) The ZERO BASE determined budget does, however, show a greater sensitivity than the SIP MIN budget when the changes occur primarily in the low unit cost items. (See Figures 3-19 and 3-21.) This is because the ZERO BASE method tends to buy larger quantities of the low cost items than does the SIP MIN approach.

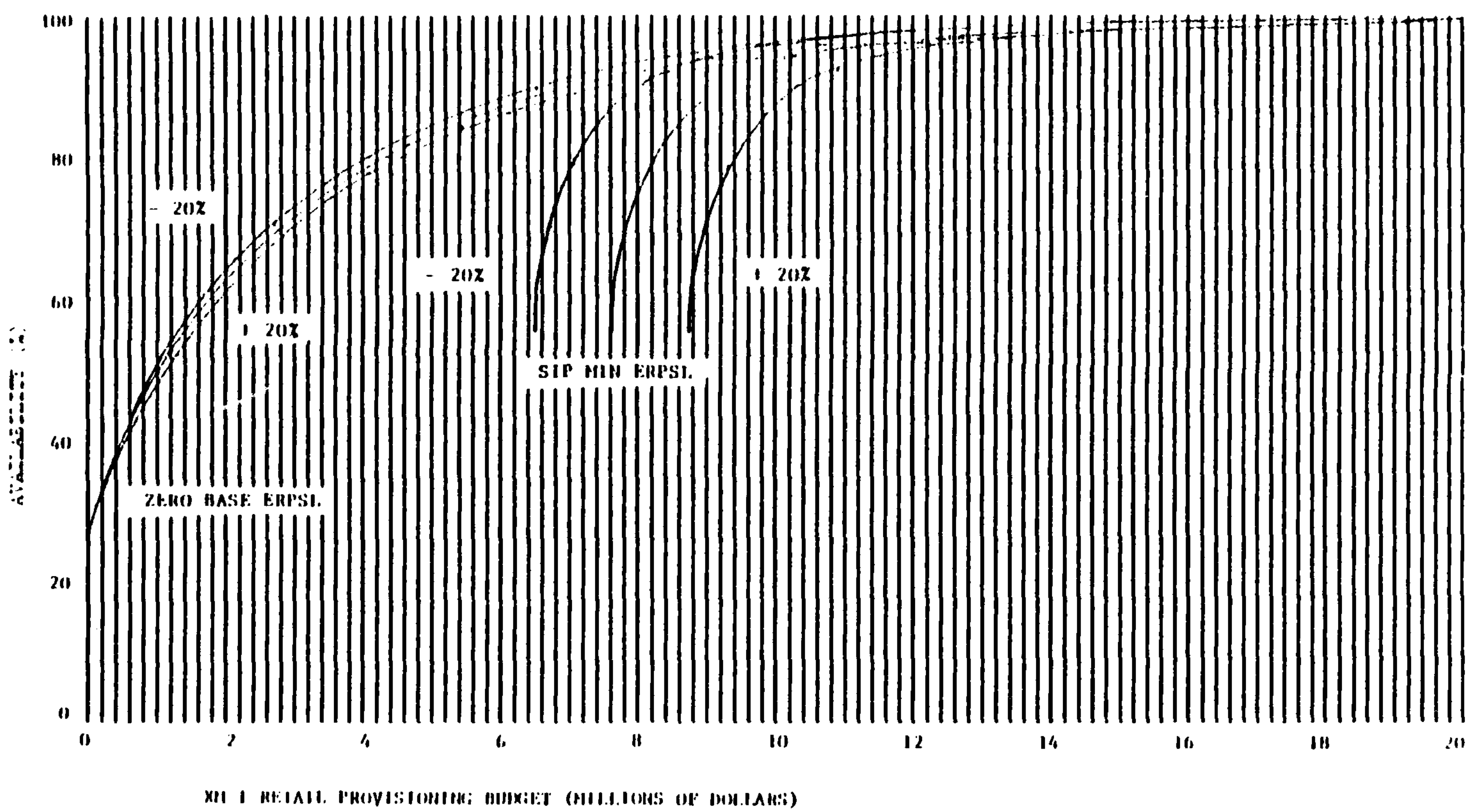


FIGURE 3-14. ± 20% UNIT PRICE CHANGE, HIGH UNIT PRICE

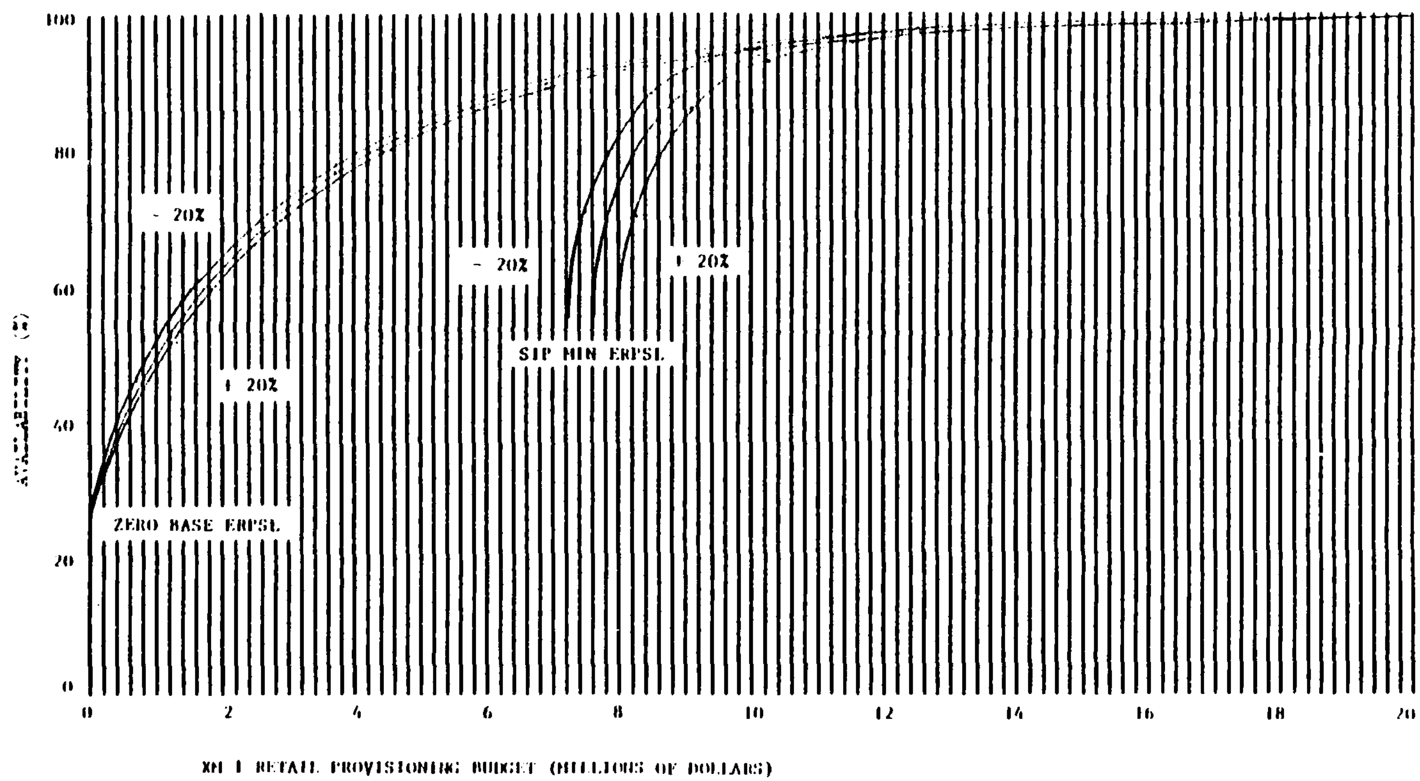


FIGURE 3.15. ± 20% UNIT PRICE CHANGE, HIGH FAILURE FACTOR

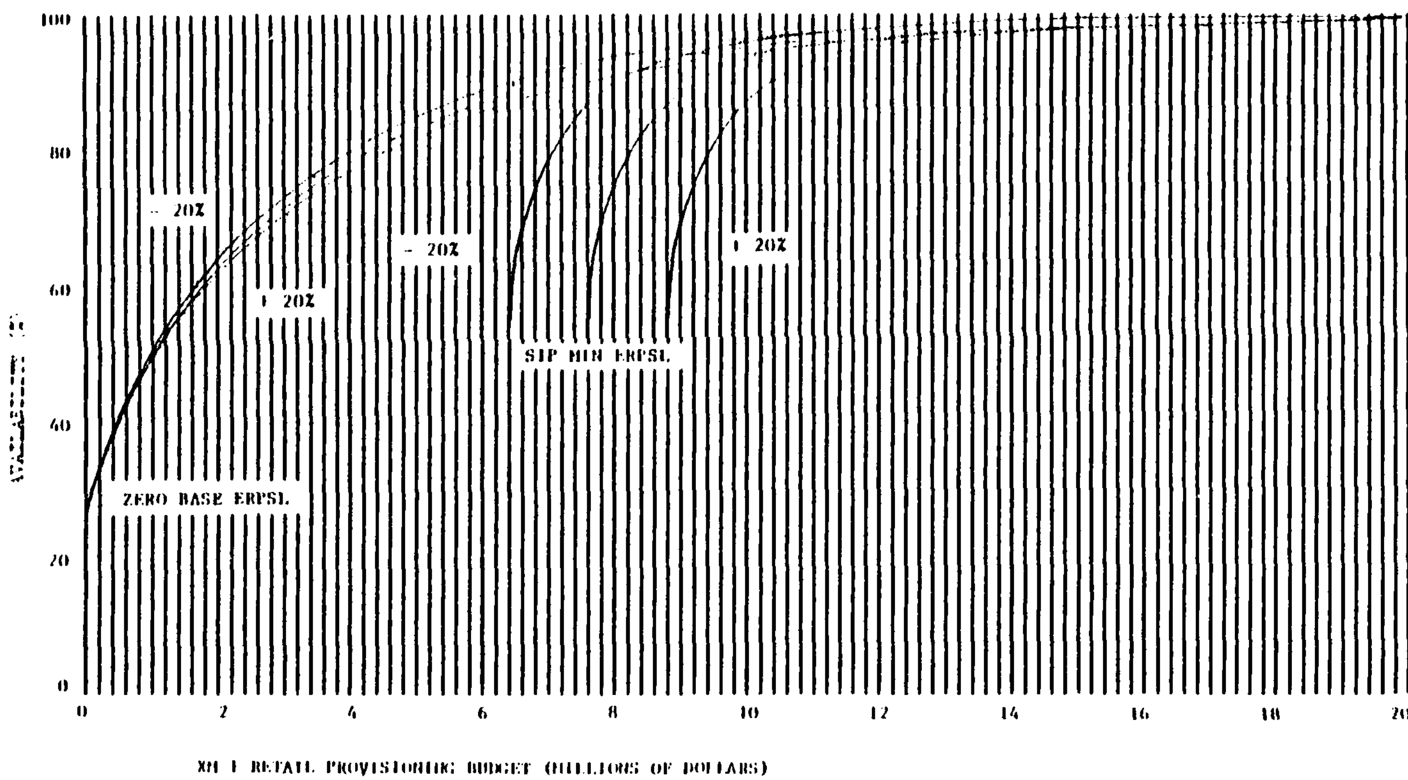


FIGURE 3 16. + 20% UNIT PRICE CHANGE, HIGH FAILURE COST

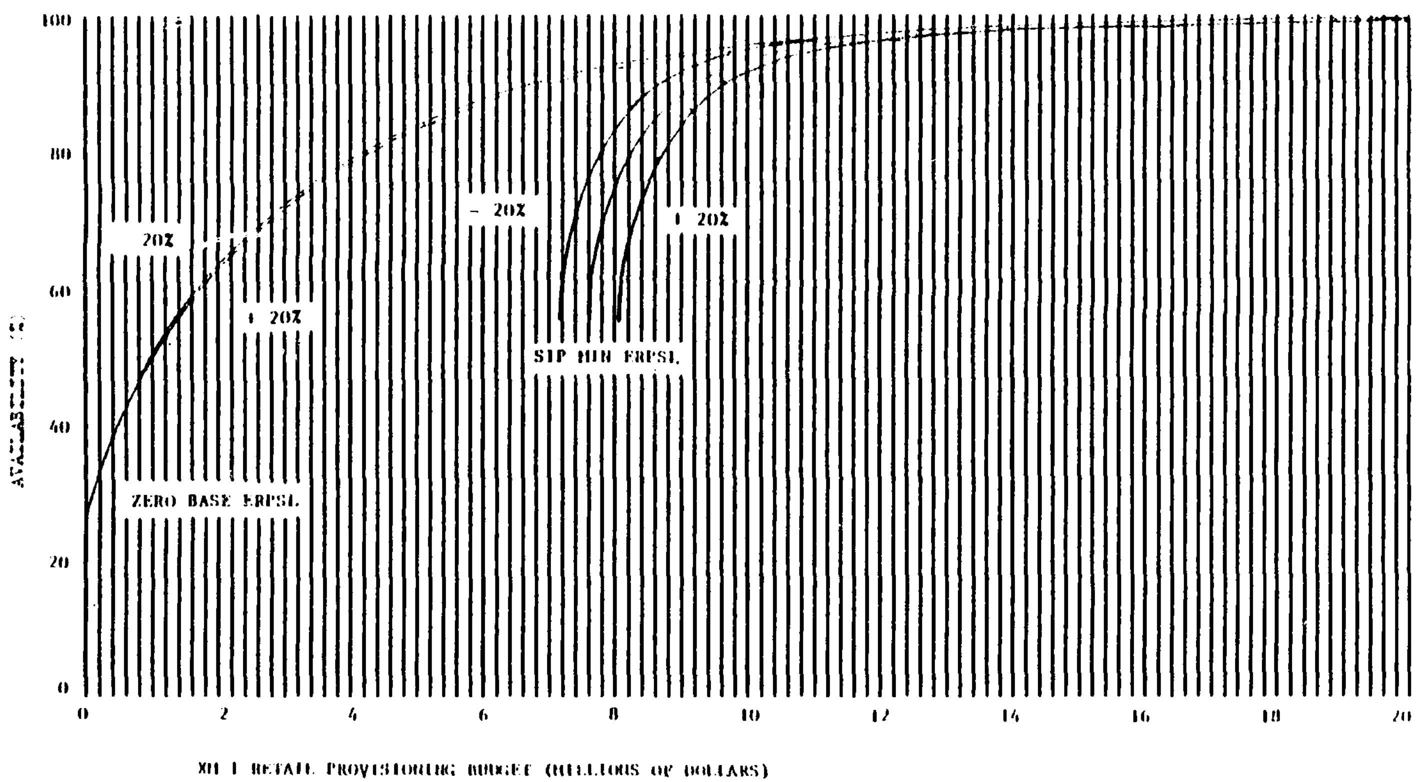


FIGURE 3-17. ± 20% UNIT PRICE CHANGE, HIGH ECP PROBABILITY

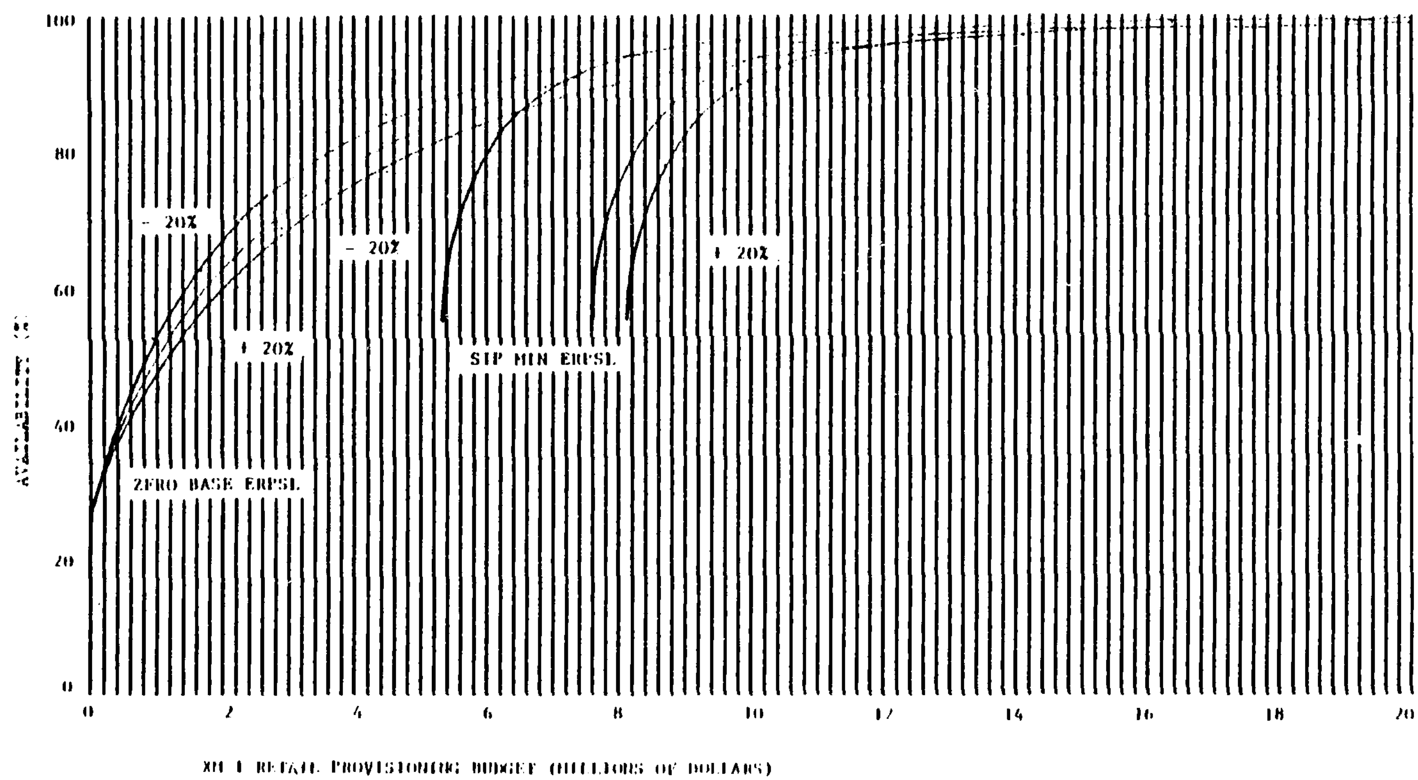


FIGURE 3-18. ± 20% FAILURE FACTOR CHANGE, HIGH UNIT PRICE

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THE USE OF AVAILABILITY MODELS IN INITIAL PROVISIONING,(U)

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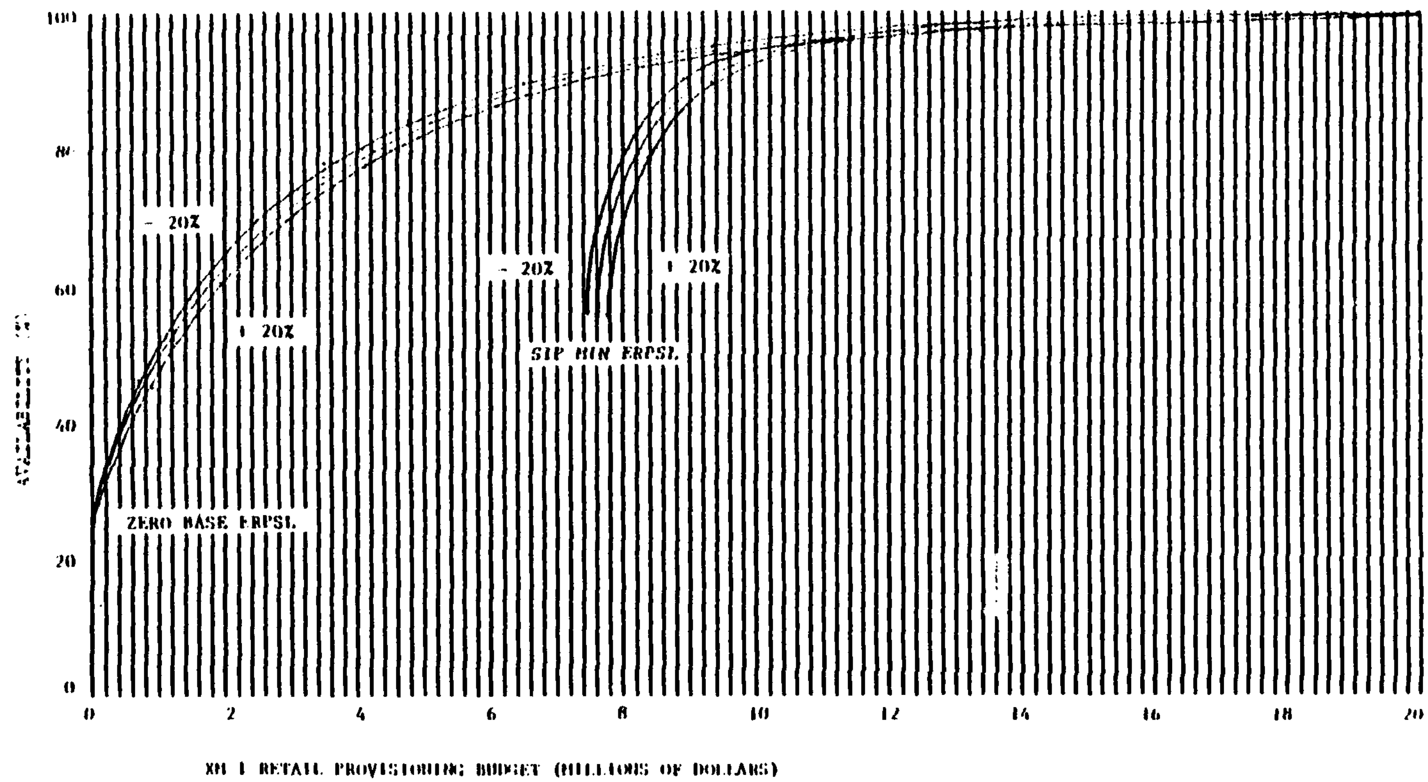

FIGURE 3-19. ± 20% FAILURE FACTOR CHANGE, HIGH FAILURE FACTOR

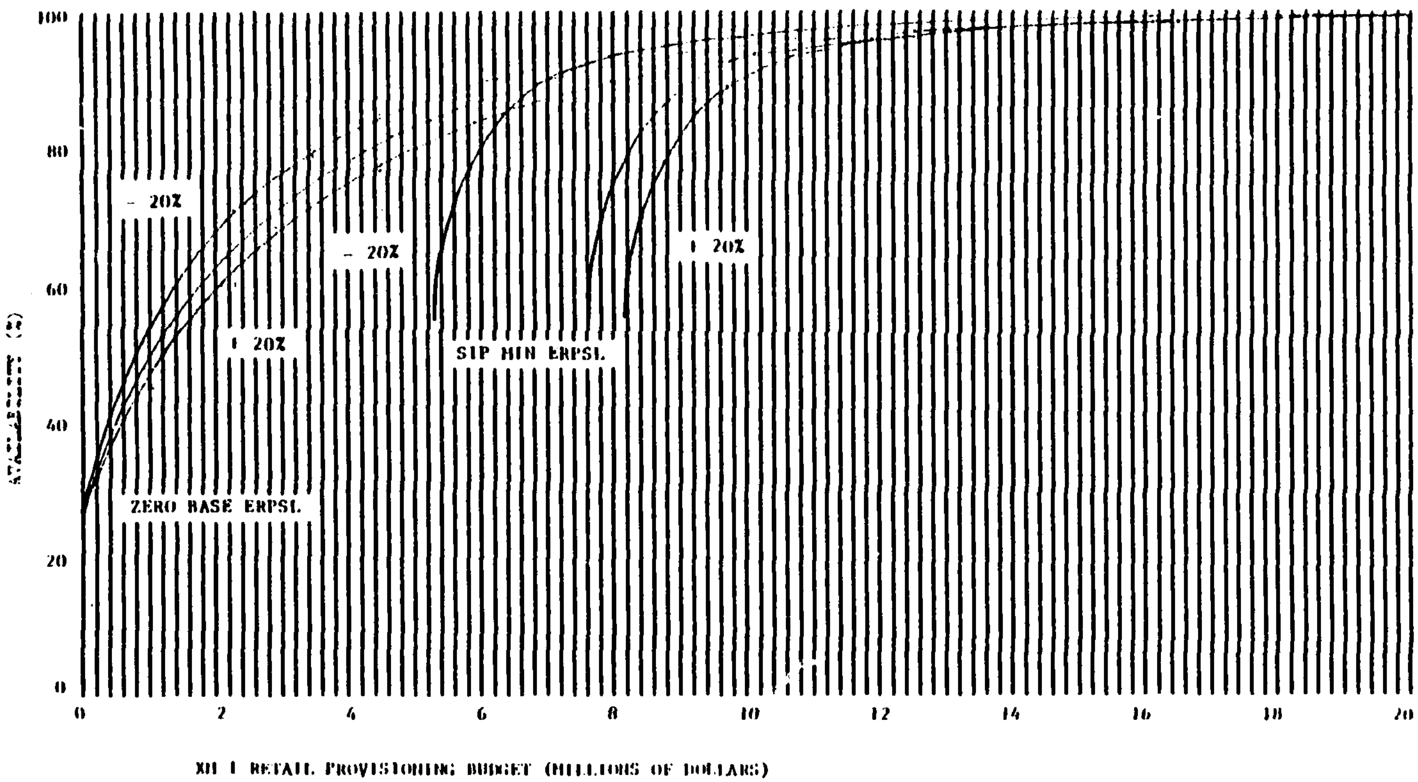

FIGURE 3-20. ± 20% FAILURE FACTOR CHANGE, HIGH FAILURE COST

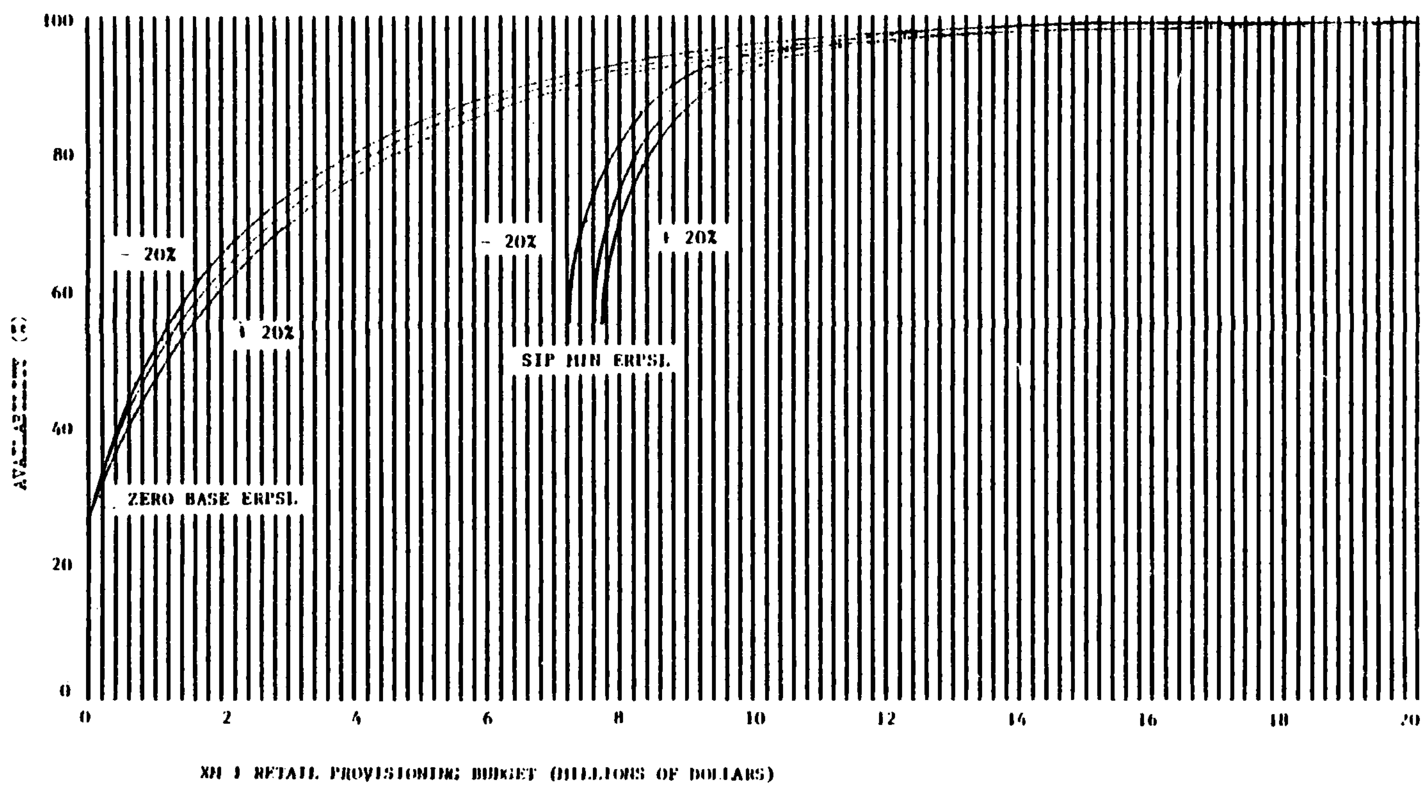

FIGURE 3-21. ± 20% FAILURE FACTOR CHANGE, HIGH ECP PROBABILITY

It should be noted, however, that the total budget excursion caused by a failure factor change to a low unit cost item is substantially less than for a high unit price item, as is shown in Table 3-7.

TABLE 3-7. BUDGET SENSITIVITY
($ Millions)

Item Subset	Variable Factor	SIP MIN -	SIP MIN Baseline Budget	SIP MIN +	SIP MIN Excursion	ZERO BASE -	ZERO BASE Baseline Budget	ZERO BASE +	ZERO BASE Excursion
High Unit Price	±20% UP	7.10	8.25	9.40	2.30	4.00	4.30	4.55	.55
	±20% FF	6.05	8.25	8.85	2.80	3.60	4.30	4.95	1.35
High Failure Factor	±20% UP	7.90	8.25	8.70	.80	4.10	4.30	4.50	.40
	±20% FF	8.10	8.25	8.50	.40	4.00	4.30	4.60	.60
High Failure Cost	±20% UP	7.05	8.25	9.45	2.40	4.00	4.30	4.60	.60
	±20% FF	6.00	8.25	8.85	2.85	3.55	4.30	5.00	1.45
High ECP Probability	±20% UP	7.80	8.25	8.75	.95	4.20	4.30	4.30	.10
	±20% FF	7.90	8.25	8.50	.60	4.00	4.30	4.60	.60

Availability Sensitivity. The effect of unit price and failure factor changes on availability for a fixed budget is perhaps an even better indicator of the real effect of uncertainty in the initial provisioning process. This is because provisioners must frequently try to live within the constraints of the predetermined, fixed spares budget in spite of changes which might have occurred to item data since the budget was initially determined.

The analyses show clearly that availability is less vulnerable to unit price and failure factor changes for a given budget level when the budget and spares mix were determined using the ZERO BASE METHOD (an optimization model) than when they were determined under the SIP MIN approach.

The greatest variation in availability under the ZERO BASE methodology occurs with a ± 20 percent change in failure factor for those subsets comprised of high unit price items (see Table 3-8). It may be noted that the maximum excursion of A_s in any one direction does not exceed 3.5 percentage points.

Under the SIP MIN methodology, on the other hand, the greatest variation in availability occurs with a ± 20 percent change in unit price, also for those subsets comprised of high unit price items. Here it should be noted that the maximum excursion of A_s in any one direction exceeds 36.5 percentage points. In fact, the previously determined SIP MIN baseline budget would no longer even be adequate to procure the pipeline quantities of the demand-based (SIP) spares.

TABLE 3-8. AVAILABILITY SENSITIVITY

		SIP MIN				ZERO BASE			
Item Subset	Variable Factor	+	Baseline Availability	-	Excursion	+	Baseline Availability	-	Excursion
High Unit Price	±20% UP	<55%	80%	91.5%	>36.5%*	78.5%	80%	81.5%	3%
	±20% FF	66%	80%	94%	28%	77%	80%	83.5%	6.5%
High Failure Factor	±20% UP	70%	80%	85%	15%	79%	80%	81%	2%
	±20% FF	75%	80%	83%	8%	78.5%	80%	81.5%	3%
High Failure Cost	±20% UP	<55%*	80%	91.5%	>36.5%*	78.5%	80%	81.5%	3%
	±20% FF	64%	80%	94%	30%	76.5%	80%	83.5%	7%
High ECP Probability	±20% UP	68%	80%	86%	18%	80%	80%	81%	1%
	±20% FF	76%	80%	84.5%	8.5%	78.5%	80%	81.5%	3%

*Budget insufficient even to buy SIP baseline quantity.

It is clear from this analysis that under a scenario where one must live within the constraints of a budget submitted and fixed in advance of having firm item data, a methodology which seeks to define the most cost-effective spares mix is far superior to one that determines the spares primarily on the basis of demand alone.

Critical Item Management

The greatest variations in both budget and availability occur in those subsets which are comprised of high unit price items. It is clear, therefore, that provisioning management attention should focus early on the high cost items in order to minimize the uncertainty around those items. Additionally, the models used to determine the provisioning budget and the mix of spares must explicitly take unit price into account in order to define the optimum budget level and mix. The item-oriented, demand-based methodology fails to account for unit price in determining the spares mix and is therefore highly unlikely to provide a cost-effective complement of initial spares.

Spares Management in the Field

Some of the error between forecast and actual initial provisioning requirements is attributable to spares management in the field. Initial provisioning models assume that the computed complement of spares will actually be placed at the appropriate claimants (i.e., a push system of initial provisioning); however, supply managers have some discretion when it comes to actually acquiring the unit's complement of initial spares (i.e., a pull system of initial provisioning). In some instances, claimants order quantities of items significantly different from those determined by an optimization model or defined by the unit's Selected List of Authorized Components. Since the unit is not required to pay for APA secondary items, there may be a motivation at some units to increase their insurance against stock-outs by

acquiring extra APA secondary items above and beyond the authorized levels without returning a like item to the depot. Although this practice may not be widespread it could have an impact on the difference between expected and actual demands. The SESAME ERPSL methodology has a built-in compensation capability for this phenomenon through adjustment of the unserviceable return rate (URR) input to the model.

CONCLUSION

The conclusion from these sensitivity analyses is clear and reinforces the simplistic example in Chapter One: an optimized stockage posture is significantly less vulnerable to uncertainty than one determined with an item-oriented technique.

The implication of this conclusion is that, when faced with a paucity of reliable data, one needs an availability model even more than in the relatively steady-state world of spares replenishment.

4. POLICY ISSUES, CONCLUSIONS, AND RECOMMENDATIONS

Several conclusions emerge from the evidence presented in this report. In this final chapter we discuss our view of the initial provisioning problem, draw conclusions about provisioning policies and the implementation of those policies, and recommend changes that we believe would enhance the cost-effectiveness of initial provisioning throughout the DoD.

The fundamental purpose of acquiring spares is to support some desired level of weapon-system availability. In the IP scenario, that desired level of availability may change over time depending on the military essentiality of the system, the need for available end items to support training and operational requirements, and the costs associated with various levels of availability. As we pointed out in Chapter 1, an availability model can be a powerful tool in establishing availability objectives because it can explicate the relationship between availability and spares cost. Furthermore, an availability model will compute that relationship in the form of an availability-vs.-cost curve, each point of which is an optimum in the sense that it represents the stockage policy that maximizes availability for that level of investment and minimizes the investment required for that level of availability. Thus, it facilitates a decision-making strategy that consists of: (a) establishing availability goals for a system in full light of the cost of any specific availability level, and (b) developing a stockage posture that requires the least possible spares investment consistent with those availability goals. Again, we assume in this discussion the availability of component-level data.

We view the provisioning process as taking place over a continuum of time. At the start of the process, component characteristics are a matter of greater uncertainty than they will be later in the system's life; but, clearly, there is no point in time when uncertainty suddenly vanishes and, somehow, truth appears. Rather, the provisioning for, say, the first year's production may be based largely on engineering estimates. As time passes and more test and operational data become available, estimates of component characteristics should be modified. We believe that it is important that judgmental data, past experience, and test and operational data be pooled in an optimal way to explicate the uncertainty surrounding estimates of component characteristics. The ability to do this will enable an availability model to develop stockage postures that are less vulnerable to uncertain futures than are postures developed by item-oriented techniques.

Finally, we see the replenishment problem as simply an extension of the provisioning problem with no sharply *defined demarcation* between them, at least in a conceptual sense. Obviously, the spares requirements computation may transition from one method, model or system to another but we believe that to be simply a matter of implementation, not a matter of fundamental conceptual change.

DoD DIRECTIVE 4140.40

DoDD 4140.40, Basic Objectives and Policies on Provisioning of End Items of Materiel, sets forth basic objectives and policies governing the provisioning for initial support of end items of materiel for which a DoD maintenance capability is anticipated. According to this document:

> The principal objective of provisioning is to assure the timely availability of minimum initial stocks of support items at using organizations and at maintenance and supply activities to sustain the programmed operation of end items until normal replenishment can be effected, and to provide this support at the least initial investment cost.

We conclude that the item-oriented procedure of DoDI 4140.42 is not consistent with this basic objective since the resulting stockage posture does not provide support at minimal initial stockage levels for the least initial investment cost.

This directive also contains policy designed to constrain the initial provisioning of a class of items, insurance items, to minimal quantities for those insurance items with unit cost $10,000 or less, and to zero otherwise. Our analyses have shown that any policy that artificially constrains stockage of an item will not, in general, be as cost-effective as one that does not.

DoD INSTRUCTION 4140.42

DoDI 4140.42, Determination of Initial Requirements for Secondary Item Spare and Repair Parts, is intended to implement the policies of DoDD 4140.40 by establishing stockage criteria for wholesale and retail levels of inventory. This DoDI presents an item-oriented computational procedure for determining stockage postures.

Readiness

The item-oriented methodology described in DoDI 4140.42 does not consider readiness, as reflected by end-item availability, in determining the range or depth of stockage. In meeting DoD's IP objective of providing support at the least initial investment cost, the procedure depends heavily upon limiting the range of stockage as opposed to adjusting both the range and the depth of stockage, as availability models do. This limiting of the range of stockage is defended in Attachment 1 to Enclosure 3 of DoDI 4140.42 where it is stated that (1) a reduction in the range can be made without adversely affecting support, and (2) most items with support problems are in the stocked-item area. It is further stated that problem items often develop as a result of engineering deficiencies which were not anticipated and which were

not greatly ameliorated by the fact that the item was stocked. The depth of stockage for high-cost items will generally be higher for a demand-based, item-oriented approach than the depth resulting from an availability model using the same investment level. Therefore, availability models result in more conservative stockage levels of these items (and higher system availabilities) than those resulting from the item-oriented approach of DoDI 4140.42 which seeks conservatism through limiting the range of stockage.

Our analyses of alternative stockage postures have shown that procedures that do not explicitly take availability into consideration are not, in general, as cost-effective as procedures that provision based on both unit cost and end-item availability.

Wholesale and Retail Stockage

The DoDI 4140.42 procedure prescribes the determination of the wholesale stockage posture and the retail stockage posture independently. As demonstrated in Chapter 1, that approach also suboptimizes the resulting stockage posture.

Other constraints placed on stockage by DoDI 4140.42 are:

(1) the restriction of insurance-type items to wholesale stockage at minimum quantities,

(2) the restriction of NSO items to below-depot echelons and at minimum quantities,

(3) the limiting of retail stock to a pipeline's worth of spares without safety stock, and

(4) the limiting of wholesale stockage requirements to a pipeline plus a three-month procurement cycle/safety level.

An availability model will compute the least-cost mix of spares for a specified availability or will maximize availability for a specified investment. Constraints that alter the computed stockage posture result in

solutions that are less cost-effective; therefore, such constraints are counterproductive and should be eliminated.

Stockage Categories

The instruction defines two basic categories of items: demand-based items and non-demand based items. The former are items with anticipated recurring demands; the latter are (1) insurance-type items (essential items that are stocked despite the absence of anticipated demand resulting from normal wear), and (2) NSO items (essential items that are stocked despite their failure to meet stockage criteria due to low probability of demand).

Availability models do not stock items based on demand rate alone, but take a system view in stocking items dependent upon their contribution to end-item availability as well as their unit cost.

Authorization of Availability Models

DoDI 4140.42 authorizes the use of availability models that provide for a different mix of spares than that resulting from the item-oriented approach, providing that the following criteria are met:

(1) An optimization technique developed to minimize system downtime or expected (time-weighted) backorders is used.

(2) No lower limits are placed on requirements that will result in stockage, as a demand-based item, of an item that would not be stocked without the lower limits.

(3) A monetary base point is determined indicating the approximate value of the requirement in accordance with the instructions.

Criterion 1 is straightforward. Criterion 2 is somewhat confusing if we assume that a true optimization model would (a) not make a distinction between demand-based and non-demand-based items as long as both were essential, and (b) not introduce lower limits since they might act to inhibit the optimization process. Criterion 3 is also confusing since it is not clear whether the monetary base point should operate as an active constraint or simply as a reference budget.

The Army's SESAME model exemplifies the confusion over the interpretation of Criterion 3. Not only does SESAME use the budget level resulting from 4140.42 as a baseline; it also uses the range and depth of stocked items as an initial condition and then optimizes the additional stock levels. We believe that this interpretation violates both the letter and intent of Criterion 3 and other DoDI 4140.42 references to the use of optimization models; yet we are not certain of the intent of Criterion 3.

RIMSTOP

RIMSTOP, Retail Inventory Management Stockage Policy, restricts stockage of non-demand based items to only one intermediate (between consumer and wholesale) echelon.

The Army implements RIMSTOP on all systems where initial provisioning requirements are computed by other than the item-oriented procedure of DoDI 4140.42. The RIMSTOP constraint, as implemented in SESAME, limits the ERPSL stockage to only one additional retail echelon beyond the SIP-stocked echelons. This interpretation of RIMSTOP is not consistent with the definition of RIMSTOP given above because it allows stockage at more than one intermediate echelon.

We have stated before that any policy that constrains the distribution of spares hinders the optimization process and thus tends to result in a stockage posture that is less than optimal.

RECOMMENDATIONS

We recommend that the ASD(MRA&L):

1. Require specification of availability goals and computation of availability-vs.-cost curves and initial provisioning stockage postures for

all new major weapon systems for review by the DSARC prior to full-scale production.

2. Revise DoDI 4140.42

   (a) to require the use of availability models and availability-vs.-cost curves in initial provisioning for all new major weapon systems,

   (b) to remove any constraints that force availability models to deliver suboptimal stockage postures, and

   (c) to require that all echelons of the logistics system be treated as an integral whole in computing stockage postures.

3. Take steps to further the development of provisioning requirements computational methods that incorporate:

   (a) techniques for quantifying and modelling the uncertainty surrounding component characteristics,

   (b) techniques for estimating expected component cost where the risks of design changes and obsolescence are taken into account, and

   (c) techniques for pooling judgments about component characteristics and for modifying those judgments optimally with test and operational data.

A FINAL WORD ON IMPLEMENTATION

We make these recommendations with full knowledge of the organizational and institutional encumbrances that would inhibit their implementation. One could characterize the defense logistics system as being essentially commodity-oriented rather than system-oriented. Information, responsibilities, management, cost accounting, and virtually every other facet of the system are partitioned along commodity lines. Nevertheless, the logic of a system view is sufficiently compelling to suggest that availability models can make important contributions to weapon-system readiness even with relatively modest investment levels.

DoDI 4140.42 was published in 1974 when the state of the art in multi-echelon inventory theory was not nearly so far advanced as it now is. The LMI

Aircraft Availability Model, for example, is a multi-item, multi-location, multi-echelon model that explicitly treats any number of levels of indenture as well as item commonality and optimizes both repair and investment budgets. It has been thoroughly tested and validated. Why, then, given that such tools are available, should the readiness of a major new weapon system be implicitly and invisibly determined by trying to estimate item pipelines with the same unreliable data people argue aren't good enough to support an availability model? Poor data are no excuse for using poor requirements computational methodology, especially in the face of the relatively greater vulnerability to uncertainty of the item-oriented technique.

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This study examines the application of spares optimization models to initial provisioning problems. Four case studies of Army weapon systems are included: the XM-1 tank, Patriot, Firefinder, and the Ground Laser Locator Designator (GLLD). It conclu des that DoD policy be changed to require the use of spares optimization models in initial provisioning and suggests modifications to the Army's implementation of DoD Instruction 4140.42.

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